A

LABORATORY COMPANION

IN

PHYSICS

FOR

HIGH SCHOOLS.

PART I.

MECHANICS, HYDROSTATICS AND HEAT,

FOR

CLASS IX.

BY

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"*The fear of the Lord is the beginning of knowledge*"

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1915

DEDICATED

BY

KIND PERMISSION

TO

H M. C HARRIS Esq., B. A., L. C. P.

AS A SMALL TRIBUTE

TO HIS ZEAL, DEVOTION AND ENERGY

WITH WHICH

HE HAS ORGANISED

THE AJMER GOVERNMENT HIGH SCHOOL

ON

MODERN LINES.

PREFACE.

This work is an attempt to meet the requirements of Matriculation and School Leaving Certificate candidates, and covers the course in Physics prescribed for these two examinations. The description of all the experiments is concise and complete and in the simplest language, and the method of recording the results in the Laboratory Note-book has been shown in detail The book, as its name implies, is thoroughly experimental in character, and by its use the pupil will gain first-hand information of simple physical truths by performing the experiments himself Necessary theory, mathematical or otherwise. either leading to the experiment in question, or important in itself, has also been systematically given The book can, therefore, be used both as a class book and laboratory manual At the end of each chapter numerical examples of different types have been given, and difficult examples have been fully solved. The student is advised to work these examples as often as he can. In order that he may also know the extent of the reading expected of him, examination questions, selected from Allahabad Matriculation papers, have also been given at the end of each chapter All the diagrams have been drawn in outline so that the student may be able to draw neatly and quickly any of the diagrams when required to do so. Every effort has been made to make the book useful to the student, and it is hoped that this work will form a sound introduction to the Intermediate course in Physics.

I beg to express my obligations to the friends who have kindly helped me in this work I am obliged to Professors Bishambar Prasad Mathur, B A, M Sc, and Lalji Srivastav, M Sc, for useful advice and criticism My warmest thanks are due and respectfully tendered to the Rev Geo Carstairs, M A., B D, for reading the manuscript and for valuable suggestions, and to the Rev W A Murdoch, M A, for kindly reading through the proofs I am under special obligation to Mr H M C Harris, B A, L C P, for the continued interest he has so very kindly shown in this work

I shall be glad to receive corrections whether of misprints or of actual errors, and to consider any suggestions for the improvement of the work

Ajmer,
15th July, 1915

B D R

CHAPTER I.

MECHANICS.

Unit of length. Two standards of length are generally used, (1) the **British Yard**, (2) the **Metre**.

The **British Yard** is the distance at 62°*F* between the centre marks in two gold plugs in a bronze bar, kept in the Standards Department of the Board of Trade at Westminster

12 inches	=	1 foot
3 feet	=	1 yard.
1760 yards	=	1 mile

The **Foot** is the unit of length employed in scientific investigations.

The Metre is the length at $0°C.$ of a platinum bar made by Borda, and kept at Paris.

10 millimetres	=	1 centimetre.
10 centimetres	=	1 decimetre.
10 decimetres	=	1 metre
10 metres	=	1 decametre
10 decametres	=	1 hectometre.
10 hectometres	=	1 kilometre
10 kilometres	=	1 myriametre.
100 centimetres	=	1 metre
1000 metres	=	1 kilometre.

The **Centimetre** is the unit of length employed in scientific investigations

The Metre was originally intended to be the ten-millionth part of the distance between the North Pole and the Equator measured along the meridian of Paris but further investigation has shown that there was a slight error in the calculation The standard metre is about an eighth of a millimetre shorter than it was meant to be.

The British yard has no scientific origin.

The chief advantage of the metric system is that all the multiples and submultiples of the unit are given by powers of ten. It is a decimal system and so reduction and calculation are much simplified.

1 metre = 1·0936 yards = 39·37 inches.
1 centimetre = ·3937 inch.
1 inch = 2·54 centimetres.

EXPERIMENT No 1 To find the diameter of a sphere by means of a scale and two rectangular blocks of wood with level faces.

Place the scale flat on the table and place the blocks alongside the graduated edge of the scale Introduce the sphere between the blocks and slide them until the sphere is firmly held between the faces which stand at right angles to the scale Read the scale opposite the touching ends of the blocks The

difference between the readings gives the diameter of the sphere

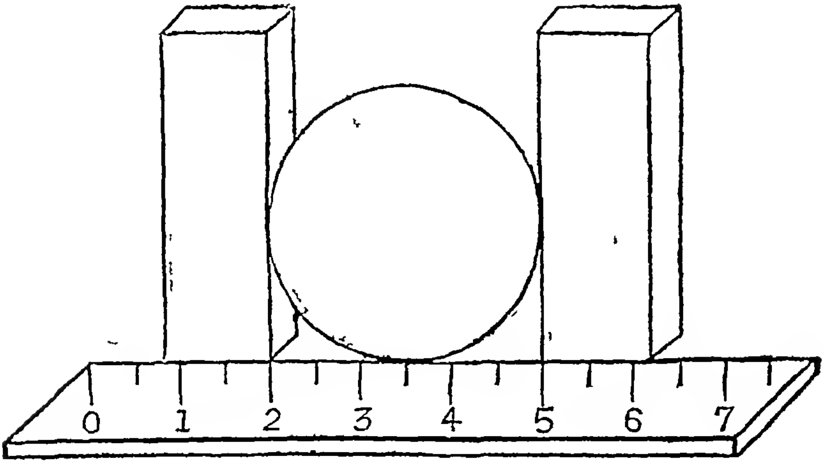


Fig 1

The diameter of a cylinder may be found in the same way

Enter your results on the right-hand page of your practical note book thus —

Date____________

Experiment. To find the diameter of a sphere by means of a scale and two rectangular blocks of wood with level faces

Apparatus. A scale, two rectangular blocks of wood with level faces, a sphere

Observations. (1) Reading of the scale opposite the first touching face 2 *cms*

(2) Reading of the scale opposite the second touching face 5 *cms*

Result. The diameter of the sphere 3 *cms.*

SLIDING CALIPERS.

This instrument consists of a straight bar of steel on which is engraved a scale in millimetres. At right angles to this bar are two jaws with flat and parallel faces. One jaw is fixed at one extremity

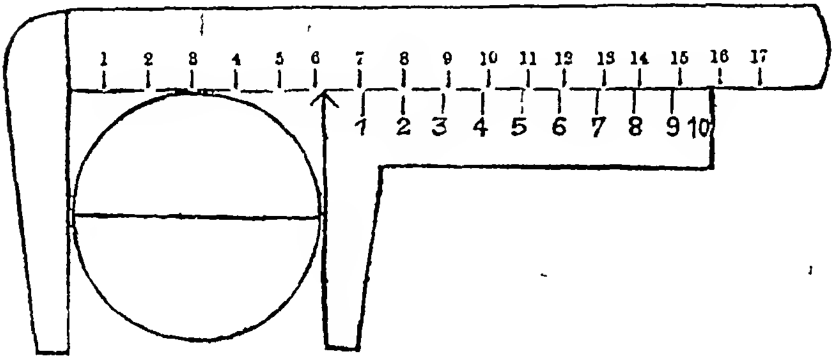


Fig 2

and the other jaw can slide along the bar. To the sliding jaw, a scale, called a vernier, is attached. The vernier scale is divided into 10 equal parts so that the ten divisions of the vernier are equal to nine divisions of the scale. There is an arrow-head at the zero division of the vernier, and when the jaws are in contact, the flat faces touch each other and the arrow-head coincides with the zero division of the scale Each division of the main scale is one millimetre and therefore each division of the vernier is $\frac{9}{10}$ *mm*. The difference between one division of the scale and one division of the vernier is $\frac{1}{10}$ *mm*. The instrument is therefore capable of measuring a length accurately to ·1 *mm*.

For the sake of clearness, the divisions on the main scale and the divisions on the vernier are shown magnified in the diagram.

EXPERIMENT No 2 To measure the diameter of a sphere by means of sliding calipers

Introduce the sphere between the jaws of the calipers so that the sphere is just held firmly by the jaws. Read the scale. Suppose the arrow-head of the vernier lies between the sixth and the seventh division of the scale Therefore the diameter of the sphere is more than six millimetres and less than seven millimetres. Now find out which division of the vernier most nearly coincides with a division of the main scale. Suppose the second division of the vernier coincides with a division of the scale. Then the distance between the arrow-head and the sixth division of the scale is the difference between two divisions of the scale, namely from 6 to 8, and two divisions of the vernier, and this is equal to $2 \times \frac{1}{10}$ *mm.* $= \cdot 2$ *mm.* Therefore the diameter of the sphere is $6 \cdot 2$ *mm.*

The diameter of a cylinder may be measured in the same way.

Enter your results on the right-hand page of your practical note book thus —

Date____________

Experiment To measure the diameter of a sphere by means of sliding calipers

Apparatus Sliding calipers, a sphere

Observations (1) When the jaws are in contact, the zero of the vernier coincides with the zero of the scale

(2) When the sphere is held by the jaws, the zero of the vernier lies between the sixth and the seventh division of the scale, and the second division of the vernier coincides with a division of the scale

Calculations The scale is divided into millimetres

10 divisions of the vernier = 9 divisions of the scale.

∴ 1 division of the vernier $= \frac{9}{10}$ *mm*

∴ The difference between 1 division of the scale and 1 division of the vernier is $\frac{1}{10}$ *mm* = ·1 *mm*

The diameter = 6·2 *mm*

Result The diameter of the sphere = 6·2 *mm*.

EXPERIMENT No 3 To measure the diameter of a wire by means of a scale

Cut from the wire a large number of short pieces Let n be the number of pieces cut Place a scale flat on the table and place these pieces side by side on the scale and see what length of the scale is just covered by them Let m be the number of millimetres covered

by the pieces. Divide the number of the millimetres by the number of the pieces and the quotient gives the diameter of the wire The diameter of the wire is $\frac{m}{n}$ millimetres

Enter your results on the right-hand page of your practical note book thus —

Date____________

Experiment To measure the diameter of a thin wire by means of a scale

Apparatus Wire, a scale, a pair of cutting pliers

Observations (1) Number of pieces cut = 50

(2) Number of millimetres covered by 50 pieces = 20

Result. The diameter of the wire = 2 5 *mm* ·4 mm

SCREW GAUGE.

A screw gauge consists of a steel bracket through one end of which passes a block with a level face and through the other passes a screw One end of the screw is just opposite to the block and is also level.

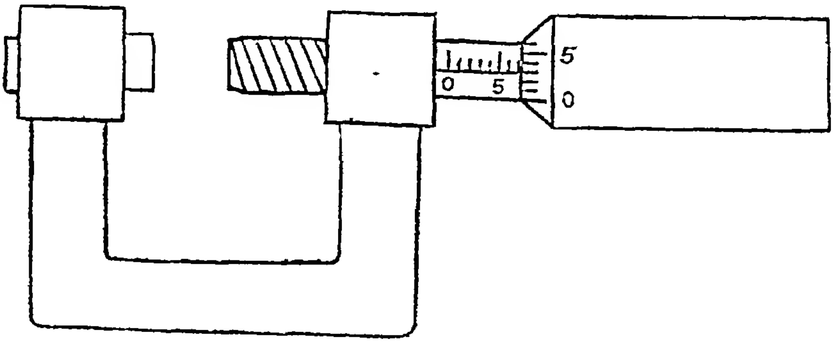


Fig 3

On the other end of the screw is a cap by means of which the screw can be turned. The circumference of the cap is divided into 100 equal parts One complete turn of the cap moves it forward or backward through one millimetre, a scale of millimetres being engraved on a stem below the cap Since one complete turn of the cap carries it through one millimetre, a turn of the cap through its one division will move it through one hundredth of a millimetre. The screw gauge is therefore capable of measuring a length to ·01 *mm.* The instrument is used for measuring the diameter of a thin wire.

In the diagram the divisions on the cap are shown magnified.

EXPERIMENT No 4 To measure the diameter of a thin wire by means of a screw gauge.

First test the zero reading This can be done by gently turning the cap till the jaws just touch each other and then taking the reading. This is the zero reading or zero correction. Having determined the zero reading, hold the wire between the two jaws and turn the cap gently till the wire is just held by the jaws, taking care never to screw the instrument too hard. Take the reading again Then add or subtract the zero reading as the case may be. The sum or the difference of the two readings gives the diameter of the wire

Suppose that when the jaws just touch each other, the zero of the cap lies between the zero and the first divisions of the stem, and the second division of the cap coincides with the horizontal line on the stem. On comparing the stem scale with a millimetre scale, it is found that the stem scale is divided into millimetres The cap is divided into 100 equal parts One complete turn of the cap, *i. e.* a turn through its 100 divisions carries it through 1 *mm* Therefore a turn through two divisions of the cap has moved it through ·02 *mm.* Therefore the zero reading is ·02 *mm*

Again suppose that when the wire is just held by the jaws, the zero of the cap lies between the 7th and the 8th divisions of the stem and the third division of the cap coincides with the horizontal line on the stem. Therefore the reading when the wire is just held by the jaws is 7·03 *mms.* Therefore the diameter of the wire is 7·03 − ·02 = 7·01 *mms.*

Enter your results on the right-hand page of your practical note book thus —

Date____________

Experiment To measure the diameter of a thin wire by means of a screw gauge

Apparatus. Wire, a screw-gauge

Observations (1) When the jaws just touch each other, the second division of the cap coincides with the horizontal line on the stem

(2) When the jaws just touch the wi
zero of the cap lies between the se
and the eighth divisions of the stem, a
the third division of the cap coincides
with the horizontal line on the stem.

Calculations. Comparing the scale on the stem with a millimetre scale, it is found that the stem scale is divided into millimetres.

One complete turn of the cap carries it through 1 millimetre

∴ The turn of the cap through its one division carries it through 01 *mm*

∴ The zero reading is 02 *mm*

And the reading when the jaws just touch the wire is 7 03 *mms*

∴ The diameter of the wire is 7 03 − 02 = 7 01 *mms.*

Result. The diameter of the wire = 7 01 *mms*

Caliper-Compasses or graduated circular Calipers

the

This instrument consists of two curved pieces of steel jointed nearly at the middle so that the thinner ends, called jaws, can be opened or closed A curved scale in millimetres is engraved on one side of one thicker end, and a similar scale in inches and tenths of an inch is engraved on its opposite side, the zero of each scale being in the centre. The other thicker end has a vertical line engraved upon it on either side, so that when the jaws are in contact, the vertical line coincides with the zero of the scale on each side The instrument is used for measuring the dimensions of curved bodies, especially the internal and the external diameters of hollow cylinders.

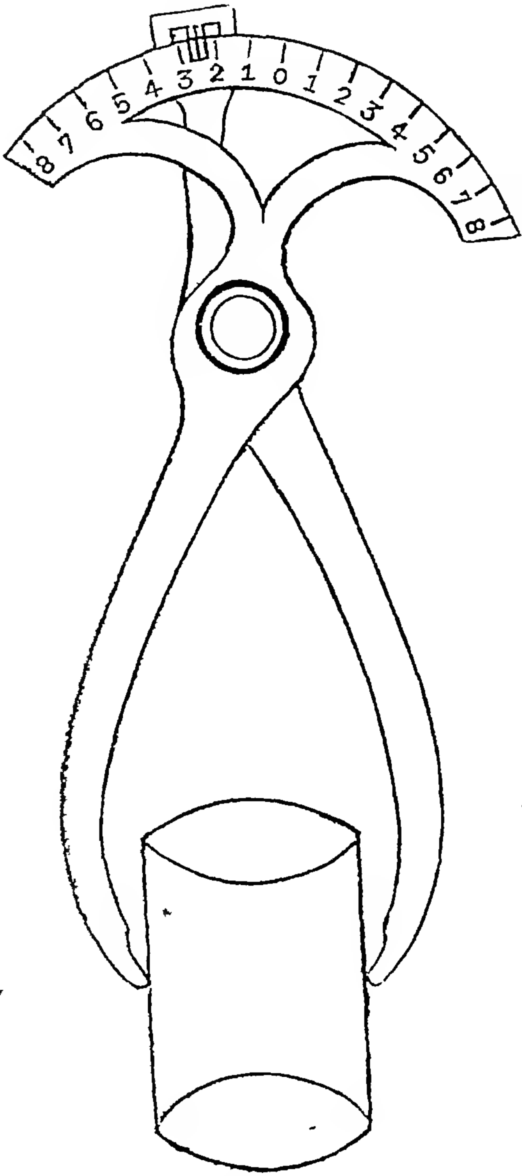


Fig 4

Subdivisions of a centimetre have not been shown in the diagram

EXPERIMENT No 5 To measure the external diameter of a circular cylinder by means of Caliper-Compasses.

Open the jaws of the circular calipers so that the distance between the jaws is a little less than the diameter of the cylinder Gently force the cylinder between the jaws so that the cylinder just passes between them Read the scale. The reading gives the diameter of the cylinder.

The diameter of a cylinder too large to fit into a pair of calipers may be found by means of a scale and two rectangular blocks of wood (See Experiment No 1, page 3)

Enter your results on the right-hand page of your practical note book thus —

Date ____________

Experiment To measure the external diameter of a cylinder by means of Caliper Compasses

Observations (1) Reading when the jaws are in contact 0 *mm*

(2) Reading when the cylinder just passes through the jaws 24 *mms*

Result The diameter of the cylinder = 24 *mms*

EXPERIMENT No 6. To measure the internal diameter of a hollow cylinder by means of Caliper-Compasses

Press the jaws of the Caliper-compasses past each other so that the distance between the jaws is a little less than the internal diameter of the cylinder Place the jaws inside the cylinder and press the jaws till they touch the sides of the cylinder Take the reading The reading gives the internal diameter of the cylinder.

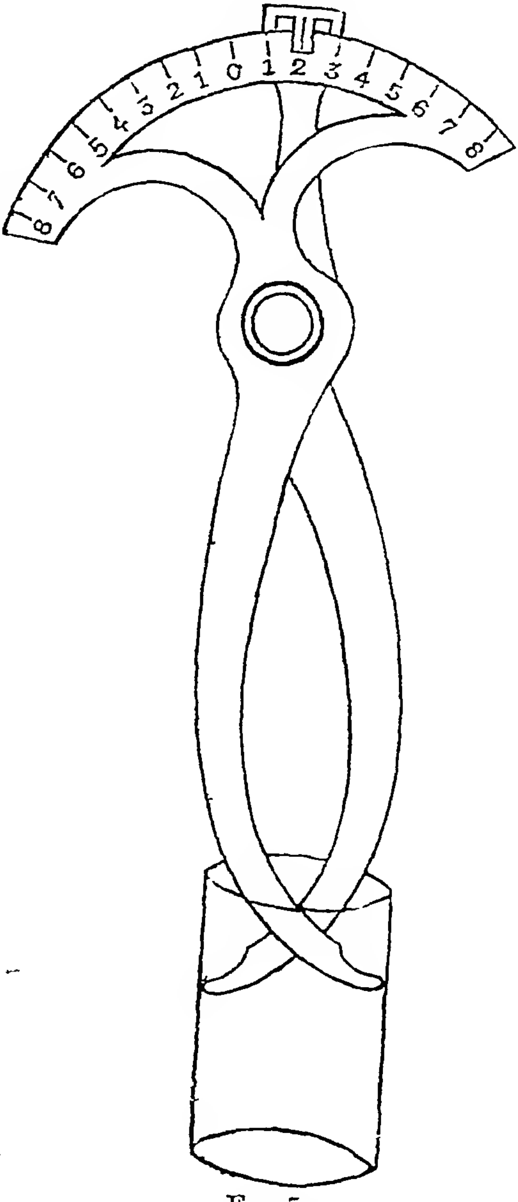


Fig 5

Enter your results on the right hand page of your practical note book thus —

Date__________

Experiment. To measure the internal diameter of a hollow cylinder by means of Caliper-compasses

Apparatus Caliper-compasses, a hollow cylinder.

Observations (1) Reading when the jaws are in contact 0 *mm*

(2) Reading when the jaws touch the sides of the cylinder 20 *mms*

Result The internal diameter of the cylinder = 20 *mms*

EXPERIMENT No 7 To measure the circumference of a circle drawn on a paper

Make a fine mark on the circumference of the circle. Take a fine thread Place one end of the thread at the mark and hold it there with the nail of the left hand thumb With the right hand stretch the thread along a very short portion of the circumference and hold it down with the nail of the right-hand thumb. Now move the left-hand thumb close to the right-hand thumb, and stretch the thread over another very short portion of the circumference Proceed in this way till the mark on the circumference is reached. Now stretch the thread straight on the table and measure the length of the thread used with a scale. The length of the thread gives the length of the circumference.

The length of any other curved line may be measured in the same way.

Enter your results on the right-hand page of your practical note book thus —

Date ____________

Experiment To measure the circumference of a circle drawn on a paper

Apparatus. A fine thread, a circle drawn on a paper

Observation The length of the thread used = 8·2 *cms.*

Result. The circumference of the circle = 8 2 *cms*

EXPERIMENT No. 8. To measure the circumference of a circular disc.

Method I. Place a scale flat on the table. Make a fine mark on the circumference of the disc and place the disc vertically on the scale so that the mark on the circumference coincides with the zero of the scale Roll the disc along the scale till the mark on the circumference again touches the scale. Take the reading of the scale at this point. This reading gives the length of the circumference of the disc.

Method II. Wrap a narrow strip of thin paper tightly round the circumference of the disc so that the ends overlap a little. At a place where the two ends overlap, make a hole in the paper with a pin. Unroll the paper, stretch it straight on the table and measure the distance between the two holes with a scale. This distance gives the length of the circumference of the disc

Enter your results on the right-hand page of your practical note book thus —

Date____________

Experiment. To measure the circumference of a circular disc.

Apparatus. A narrow strip of thin paper, a disc, a scale, a pin.

Observation. The distance between the pin holes = 6 8 *cms.*

Result. The circumference of the disc = 6 8 *cms*

EXPERIMENT No 9 To find the ratio of the length of the circumference of a circle to the length of its diameter, and to represent the relation by means of a graph.

Take five discs of different diameters Wrap a narrow strip of thin paper tightly round the circumference of one disc so that the ends overlap a little At a place where the two ends overlap, make a hole with a pin. Unroll the strip, stretch it straight on the table and measure the distance between the pin holes. In this way measure the circumference of each disc.

Then measure the diameter of each disc by means of a pair of calipers Divide the length of the circumference by the length of the corresponding diameter, and the quotient in each case gives the ratio. This ratio will be found to be 3 1416

On a sheet of curve paper mark two straight lines OX and OY at right-angles to each other, OX horizontal and OY vertical On OX mark off OM to represent the length of a diameter, and on OY mark off ON to represent the length of the corresponding circumference Through M and N draw MP and NP parallel to OY and OX respectively, intersecting in P OM is called the abscissa of the point P and PM is called its ordinate Thus a point P is obtained whose abscissa represents the length of the diameter and whose ordinate represents the length of the corresponding circumference Thus, by graduating OX in diameter lengths and OY in circumference

lengths, plot other points also. Unite these points by

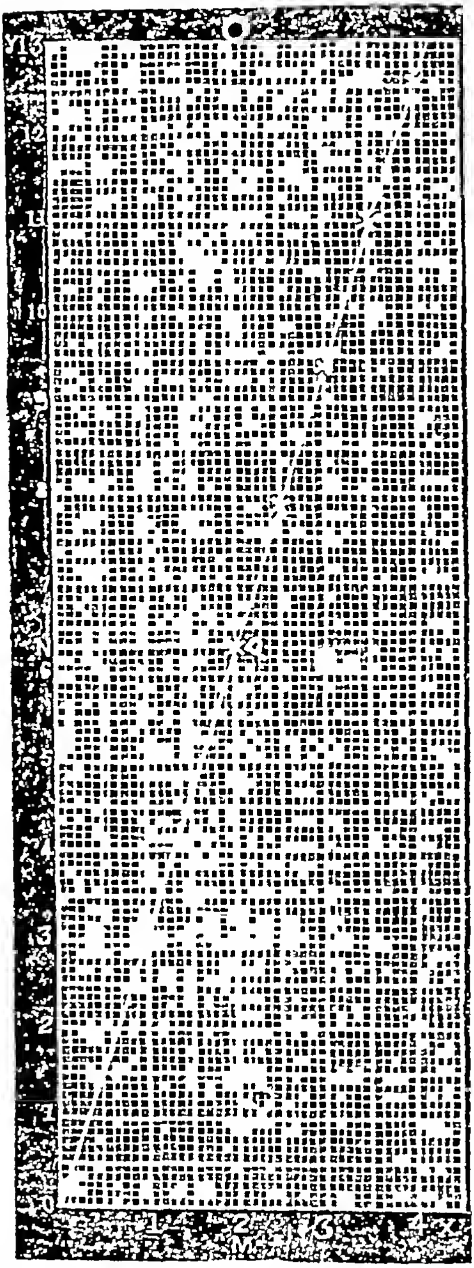


Fig 6

a curve and the curve passing through these points is the graph The graph in this case will be found to be a straight line passing through the origin O.

Enter your results on the right-hand page of your practical note book thus —

Date____________

Experiment To find the ratio of the length of the circumference of a circle to the length of its diameter, and to represent the relation by means of a graph

Apparatus. 5 discs of different diameters, a scale, a strip of thin paper, squared paper

Observations, calculations and results.

Discs.	Length of diameter	Length of circumference	Ratio
Disc No 1	2 *cms*	6·3 *cms*	3·15
Disc No. 2	2·5 *cms*	7·8 *cms*	3·14
Disc No. 3	3 *cms.*	9·4 *cms*	3·133
Disc No 4	3·5 *cms.*	11 *cms.*	3·142
Disc No. 5	4 *cms.*	12·55 *cms.*	3·137

AREA AND VOLUME.

The **unit of area** or **surface** is the area of a square each side of which is one unit long

In the British system, the unit of area is the area of a square each side of which is one yard long and this unit of area is called a **square yard**

144 square inches	=	1 square foot.
9 square feet	=	1 square yard.
4840 square yards	=	1 acre
640 acres	=	1 square mile.

In the French or Metric system, the unit of area is the area of a square each side of which is one metre long, and this unit of area is called a **square metre** or **centiare** The more generally adopted unit of area is the area of a square each side of which is 10 metres long, and this unit of area is called an **are.** For scientific purposes the **square centimetre** is the recognised unit of area.

10 centiares	=	1 deciare
10 deciares	=	1 are
10 are	=	1 decare
10 decares	=	1 hectare
1 centiare	=	10·764299 square feet

The **unit of volume** is the volume of a cube each edge of which is one unit long

In the British system, the unit of volume is the volume of a cube each edge of which is one yard long. This unit of volume is called a **cubic yard.**

1728 cubic inches	=	1 cubic foot
27 cubic feet	=	1 cubic yard

In the Metric system, the unit of volume is the volume of a cube, each edge of which is one metre long This unit of volume is called a **Stere,** and is the unit of the measures of solidity, and is used for measuring wood etc.

The **litre** is the volume of a cube each edge of which is a decimetre The litre is the unit of the

measures of capacity, dry and liquid. A litre=1000 cubic centimetres For scientific purposes the **cubic centimetre** is the recognised unit of volume.

10 millilitres	=	1 centilitre
10 centilitres	=	1 decilitre
10 decilitres	=	1 litre
10 litres	=	1 decalitre
10 decalitres	=	1 hectolitre
10 hectolitres	=	1 kilolitre
10 kilolitre	=	1 myrialitre

EXPERIMENT No 10 To find the area of a circle by means of squared paper and to check the result by means of the formula, area of a circle = πr^2.

With the point of intersection of any two thick lines on a curve paper as centre and with any given radius, draw a quadrant of a circle. Count the number of small squares each $\frac{1}{100}$ sq inch or $\frac{1}{100}$ sq. *cm* included in the boundary line, counting the square which is more than half as a full square and omitting that which is less than half Multiply the total number of squares by $\frac{1}{100}$, the product gives the area of the quadrant, and 4 times this area is the area of the circle

Measure the radius of the circle with a pair of dividers and a scale. and calculate the area by means of the formula, area of a circle = πr^2.

The area of any irregular figure which has already been drawn on a squared paper or which can be **traced** on it may be found in the same way

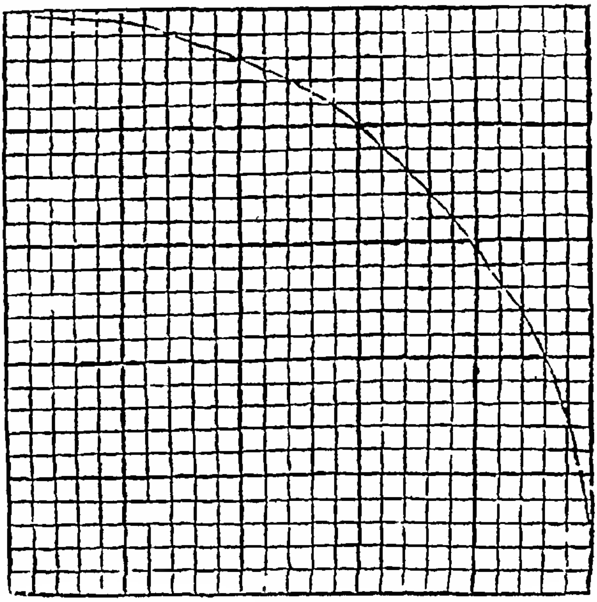


Fig 7

If the given figure is already drawn on a plain paper, and if it is not possible to trace it on a squared paper, divide the figure into a number of small equal squares by drawing two sets of parallel straight lines at right angles to one another Count the number of small squares within the boundary line, counting the square which is more than half as a full square and omitting that which is less than half Calculate the area of one of these squares and multiply this area by the total number of squares The product gives the area of the whole figure

Enter your results on the right-hand page of your practical note book thus —

Date____________

Experiment. To find the area of a circle by means of a squared paper and a pair of compasses, and to check the result by the formula, area $= \pi r^2$.

Apparatus A squared paper ruled in squares $\frac{1}{10}$ inch, a pair of compasses, a scale

Observations. (1) Radius of the circle 2 5 inches

(2) Number of small squares in the quadrant of the circle $= 491$.

Calculations. Area of a small square $= \frac{1}{100}$ square inch.

$\therefore$ Area of the quadrant $= \frac{1}{100} \times 491 = 4\ 91$ square inches

$\therefore$ Area of the circle $= 4 \cdot 91 \times 4 = 19 \cdot 64$ square inches

Area of the circle $= \pi r^2 = 3\ 1416 \times 6\ 25 = 19\ 635$ sq, inches

Results. (1) Area of the circle found by means of squared paper $= 19\ 64$ square inches

(2) Calculated area $= 19\ 635$ square inches

EXPERIMENT No 11 To find the ratio of the length of the circumference of a circle to the length of its diameter by means of squared paper and a pair of compasses.

With the point of intersection of any two thick lines on a curve paper as centre and with a convenient radius, draw a quadrant of a circle Count the number of small squares each $\frac{1}{100}$ square inch or $\frac{1}{100}$ square *cm* included in the boundary line, counting the square which is more than half as a full square and omitting that which is less than half Multiply the total number of squares by $\frac{1}{100}$, the product gives the area of the quadrant, and 4 times this area gives the area of the circle

Divide this area by the square of the radius of the circle and the quotient gives the required ratio. It will be found to be very nearly 3·1416

Enter your results on the right-hand page of your practical note book thus —

Date____________

Experiment To find the ratio of the length of the circumference of a circle to the length of its diameter by means of a curve paper and a pair of compasses

Apparatus. A square paper divided into squares $\frac{1}{10}$ inch, a pair of compasses

Observations (1) Radius of the circle = 2·5 inches

(2) Total number of squares in the quadrant = 491

Calculations. Area of a small square = $\frac{1}{100}$ square inch.

∴ area of the quadrant = 4 91 sq inches
the area of the circle = 19·64 sq inches
$r^2 = 6 \cdot 25$

$$\pi = \frac{\text{area}}{r^2} = \frac{19 \cdot 64}{6 \cdot 25} = 3 \cdot 0424$$

Result The ratio of the length of the circumference to the length of its diameter is approximately = 3 0424

BURETTE.

Description

A burette is a glass tube graduated throughout most of its length into cubic centimetres and tenths of a cubic centimetre Its lower end is provided with a stop-cock, or with a piece of india-rubber tube and pinch-cock by means of which the liquid in the burette may be run off A burette reads downwards and is used for measuring out a small volume of a liquid accurately

Method of using.

The burette is supported in a vertical position and some liquid is poured into it, and the graduation just opposite the lowest part of the curved portion of the liquid is read, keeping the line of sight horizontal

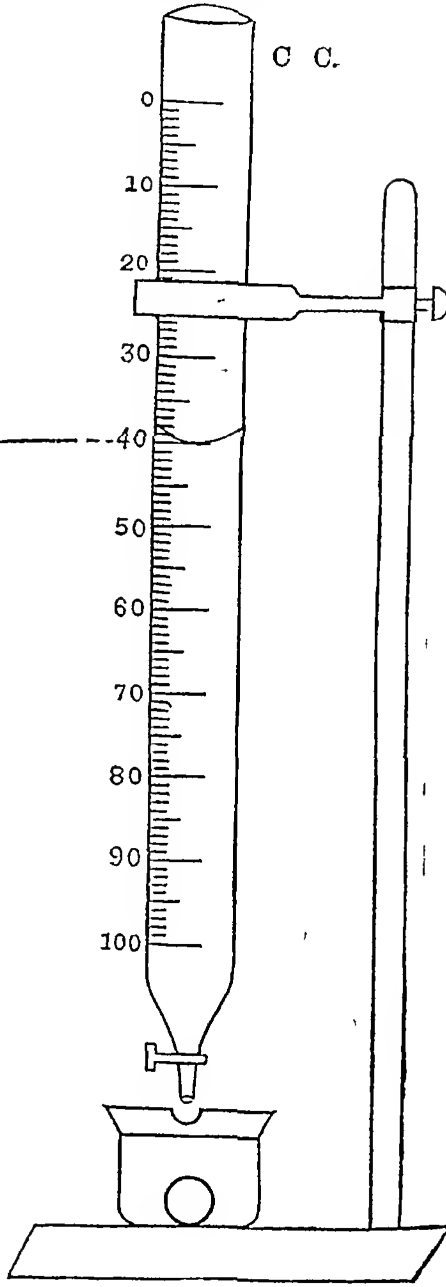


Fig 8.

EXPERIMENT No. 12. To find the volume of a sphere by means of a burette, and to verify the formula, Volume of a sphere $= \frac{4}{3}\pi r^3$

Take a small beaker and make a fine horizontal mark on its outside with a file or stick on a piece of gummed paper Fill the burette with water to its zero mark Place the sphere in the beaker and run the water into the beaker till the level of the water is up to the mark or up to the edge of the label Read the level of the water in the burette Remove the sphere and the water from the beaker Fill the burette again to its zero mark and run water from it into the empty beaker till the level of the water stands at the same mark. Read the level of the water in the burette The difference between the two readings is the volume of the sphere The volume of any irregular solid may be found in the same way.

Measure the diameter of the sphere by means of sliding calipers or by means of two blocks of wood and a scale Then calculate the volume by applying the formula, volume of a sphere $= \frac{4}{3}\pi r^3$, where $\pi = 3{\cdot}1416$.

Enter your results on the right-hand page of your practical note book thus —

Date__________

Experiment. To find the volume of a sphere by means of a burette and to verify the formula $V = \frac{4}{3}\pi r^3$

Apparatus. A burette, a beaker with a mark on it, water, a sphere, sliding calipers

Observations. (1) Reading of the burette after the water was run off into the beaker containing the sphere, 40 *C C*

(2) Reading of the burette after the water was run off into the empty beaker, 54 C C.

(3) Diameter of the sphere = 3 cms

Calculation. Volume of the sphere $= \frac{4}{3}\pi r^3$

$$= \frac{4}{3} \times 3\ 1416 \times 3\ 375$$
$$= 14\ 1372\ C\ C$$

Results (1) Volume of the sphere found by means of a burette $= 14\ C\ C$

(2) Calculated volume $= 14\ 14\ C\ C$

GRADUATED CYLINDER.

A graduated cylinder is a hollow glass cylinder closed at the bottom and graduated in cubic centimetres It is graduated by running a known volume of water successively from a burette It is used for measuring a considerable volume of a liquid and where the volume is only required to the nearest whole cubic centimetre

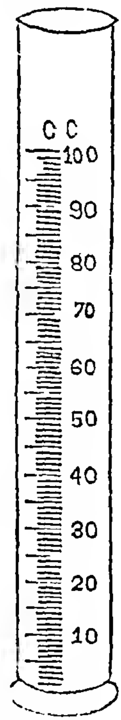


Fig 9.

EXPERIMENT No 13 To test the accuracy of the graduation of a cylinder.

Support a burette in a vertical position and fill it with water to its zero mark Place the cylinder under the tap of the burette and run from the burette 10 C C of water and read the surface of the water in the cylinder Again run 10 C C of water into the cylinder from the burette and take the

reading for the surface of the water in the cylinder Proceed in this way till the last graduation of the cylinder is reached

Enter your results on the right-hand page of your practical note book thus —

Date____________

Experiment. To test the accuracy of the graduation of a cylinder

Apparatus. A burette, water, a graduated cylinder.

Observations

Volume of water delivered from the burette	Reading for the surface of water in the cylinder
10 C C	10 C C
10 C. C.	20 C C
10 C. C.	30 C C
10 C. C.	40 C C
10 C. C	50 C C
10 C. C.	60 C C.
10 C C.	70 C C.
10 C C.	80 C C
10 C. C.	90 C C
10 C C.	100 C C

Result The cylinder is correctly graduated

EXPERIMENT No 14. To find the volume of a solid lighter than water by means of a graduated cylinder

Fill the cylinder with water and read the level of the water Take a piece of copper so that the solid when fastened to it sinks in water This piece of copper is then called a sinker Fasten the solid to the piece of copper, tilt the cylinder a little, and gently slide down the combination into the water Keep the cylinder in a vertical position, and read the level of the water The difference between the two readings gives the volume of the combination Take the combination out of the water, and read the surface of the water again Tilt the cylinder again, and gently slide down the sinker alone into the water Now keep the cylinder in a vertical position and read the surface of the water again The difference between the two readings gives the volume of the sinker The difference between the two volumes gives the volume of the lighter solid

Enter your results on the right-hand page of your practical note book thus —

Date______________

Experiment To find the volume of a piece of wax by means of a graduated cylinder

Apparatus A graduated cylinder, water, wax, a sinker

Observations (1) Reading of the cylinder when there is water only in it, 20 *C C*

(2) Reading of the cylinder when the combination is placed in the water, 28 *C C*

(3) Reading of the cylinder when there is water only in it, 20 *C C*

(4) Reading of the cylinder when the sinker is placed in the water, 23 *C. C*

Calculations. Volume of the combination = 8 *C C.*
Volume of the sinker = 3 *C C*

Result. Volume of wax = 5 *C C.*

MASS, DENSITY AND WEIGHT.

The **mass** of a body is the quantity of matter in it. Two standards of mass are generally used

The **British unit** of mass is the mass of a piece of platinum kept in the Standards Department of the Board of Trade at Westminister, and is called the **Pound Avoirdupois.** It contains 7000 grains.

437·5 grains = 1 ounce.
16 ounces = 1 pound.
14 pounds = 1 stone.
112 pounds = 1 hundred weight.
20 hundred weight = 1 ton.

The **Metric unit** of mass is the mass of a piece of platinum made by Borda and kept at Paris, and is called the **Kilogramme.**

10 milligrammes = 1 centigramme
10 centigrammes = 1 decigramme
10 decigrammes = 1 gramme
1000 grammes = 1 kilogramme

The **Gramme** is the unit of mass employed for scientific purposes

The **Gramme** was originally intended to be the mass of one cubic centimetre of distilled water at 4°*C*. The mass of a cubic centimetre of distilled water at 4°*C* is really 1·00013 gramme, but for all practical purposes it is one gramme

The British Pound has no scientific origin.

1 gram = 15 432349 grains
1 grain = 06479895 gram

F P S and C G S Systems In the British scientific system, the unit of length is the **Foot.** the unit of mass is the **Pound,** and the unit of time is the **Second,** and the system is called the F P S. system.

In the Metric system, the unit of length is the **Centimetre,** the unit of mass is the **Gramme,** and the unit of time is the **Second,** and the system is called the C G S system It is well adapted for scientific purposes

The **absolute density** or simply the **density** of a homogeneous substance at any temperature is the mass of a unit volume of that substance at that temperature The mass of a cubic foot of water is 62 321 lbs.

therefore the density of water is 62·321 lbs per cubic foot The mass of a cubic centimetre of water is one gramme. therefore the density of water is one gramme per cubic centimetre The mass of a cubic centimetre of copper is 8·95 grammes, therefore the density of copper is 8·95 grammes per cubic centimetre The absolute density depends upon the units of length and mass In F P S system the absolute density of water is expressed by the number 62·321 while in C G S system it is expressed by the number 1

If M be the mass of a substance whose volume is V, and whose density is ρ then, since the mass of a unit volume is ρ, the mass of the volume V is $V\rho$, therefore $M = V\rho$

The weight of a body is the force or pull with which the earth attracts the body to its centre The weight of a body is really measured by a spring balance, the earth's attraction for the body stretching the spring attached to the body through a certain distance An ordinary balance *i e*, a pair of scales compares masses only Two masses which are found to be equal when measured by an ordinary balance, will be found to be equal no matter where they are measured by the same kind of balance The weight of a body is exactly proportional to its mass If W be the weight of a body whose mass is M, and W_1 be the weight of another body whose mass is M_1, then $\frac{W}{W_1} = \frac{M}{M_1}$.

BALANCE.

Principle of the balance. Take a scale divided into centimetres and suspend it at its middle point from a support The scale should rest horizontally If the scale be not horizontal, stick a piece of tin foil on one side till the scale is horizontal Take a known weight from a box of weights and suspend it at a dis-

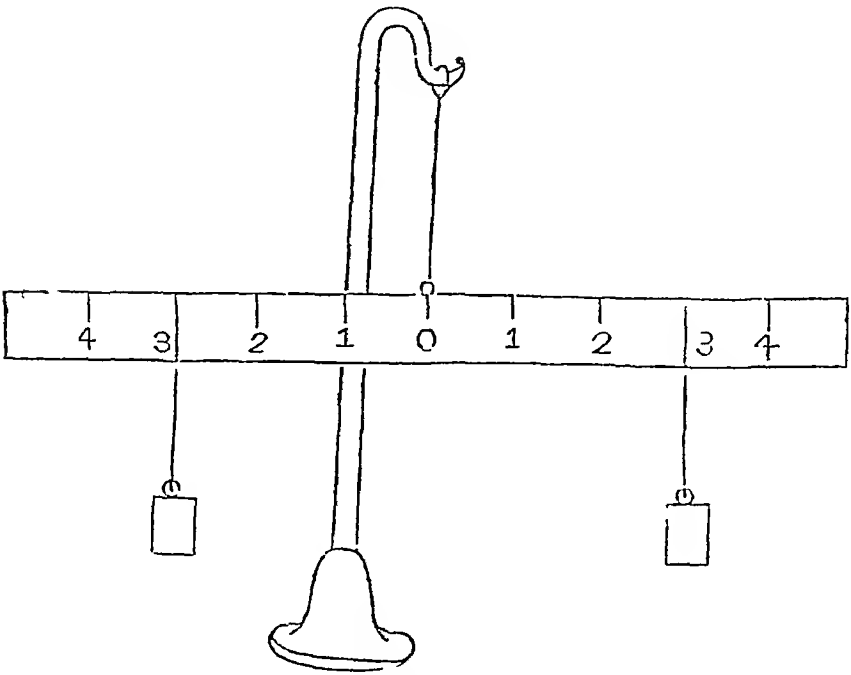


Fig 10

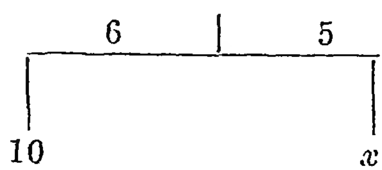
tance of 3 centimetres from the turning point (fulcrum) Suspend an **equal** weight on the other side and adjust its position on the scale till the scale is again horizontal. The distances of the masses from the fulcrum will be found to be the same on each side Remove these weights from the scale Hang a weight of 20 grams at a distance of 1 centimetre from the

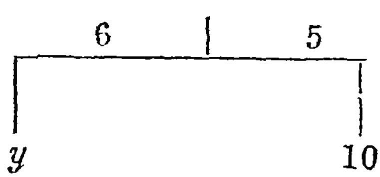
fulcrum on one side and a weight of 5 grams at a distance of 4 *cms* from the fulcrum on the other side The scale will again be found to be horizontal. Therefore it is concluded that **the mass on one side multiplied by its distance from the fulcrum is equal to the mass on the other side multiplied by its distance from the fulcrum** This is known as the principle of the Lever and is used in the construction of a balance The lever is a rigid bar which has one point fixed, about which the rest of the lever can turn. This fixed point is called the fulcrum

The common balance (not a spring balance) is constructed on this principle The two arms are equal and they are horizontal when the weights in the scale pans are eqnal

To show that a person will lose if he weighs out equal quantities of a substance alternately from each scale pan of a balance which has unequal arms and the beam of which remains horizontal when the pans are unloaded.

Let the left arm be 6 inches and the right arm be 5 inches Suppose the person wishes to weigh out 10 lbs from each pan Let the 10 lb weight be placed in the left pan and the substance in the right pan While appearing to weigh 10 lbs, he actually weighs out a quantity x such that





$$x \times 5 = 10 \times 6$$
$$x = 12.$$

so while appearing to weigh 10 lbs, he has actually weighed 12 lbs

Now let the 10 lb weight be placed in the right-hand pan and the substance in the left-hand pan, while appearing to weigh 10 lbs, he actually weighs a quantity y such that $y \times 6 = 5 \times 10$

$$y = \frac{50}{6} = 8\frac{2}{6}.$$

therefore while appearing to weigh 20 lbs, he has actually weighed $12 + 8\frac{2}{6} = 20\frac{2}{6}$ lbs therefore he has lost $\frac{2}{6}$ lb or $\frac{1}{3}$ lb

Description of a delicate balance

A delicate balance consists of a beam of brass supported at its middle line by a knife edge of hard

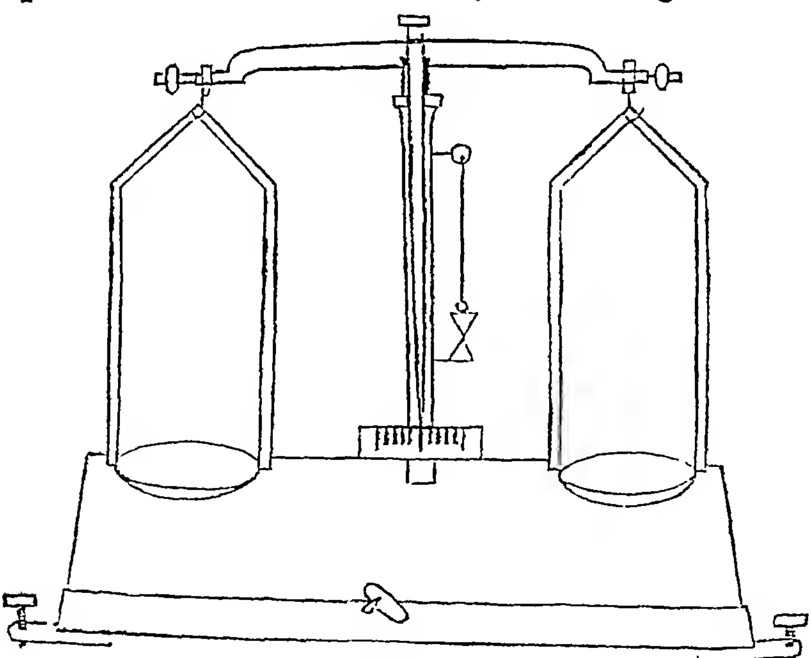


Fig 11.

steel which rests on two small steel plates fixed to the top of the pillar of the balance. At the extremities of the beam pans are suspended from small stirrups which rest on knife edges attached to the extremities of the beam. To the middle of the beam is attached a pointer the end of which moves over an ivory scale fixed to the bottom of the pillar. To the base of the board are attached levelling screws by means of which and the plummet the balance may be made level. There is an arrestment by means of which the beam can be raised or lowered.

Precautions in weighing.

(1) See, by means of the plummet, that the balance is level If it is not level, make it so by means of the levelling screws

(2) When the scale pans are empty, and when the beam is raised, see that the pointer coincides with the middle of the scale, or swings equally on either side. If not, adjust the balance by screwing out the screw-nut at the end of the beam on that side to which the pointer tends to move.

(3) Never touch the weights with the fingers, but always move them with forceps.

(4) Place the body to be weighed on the left-hand pan, and the weights on the right-hand pan.

(5) While the beam is swinging, never touch the body, or the weights, the beam must always be fixed before a weight is changed.

(6) Whenever it is necessary to lower the beam; it should be lowered only when the pointer is passing over the middle of the scale, and not otherwise

(7) Try all the weights in the order in which they are arranged in the weight box, commencing with the largest

(8) In order to find out if a weight is too much or too little, raise the beam slowly, and the first motion of the pointer will give the required information The beam should be entirely raised only when the equality of the two loads in the two pans is nearly reached

(9) Move the eye with the pointer to read its position on the scale

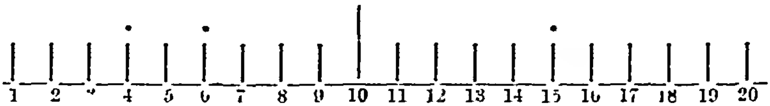
(10) When the weighing is completed, lower the beam, and replace the weights in their proper places in the box

METHODS OF WEIGHING.

(*a*) **Method of oscillations or vibrations** In a delicate balance, the pointer when once set in motion oscillates across the scale and will come to rest after some time In weighing by the method of oscillations, much time is saved and this method can easily be learned after a little practice, and it is to the advantage of the student if he makes himself familiar with this method as early as possible. The method is explained in the next experiment.

EXPERIMENT No. 15. To find by the method of oscillations, the resting point when the pans of the balance are unloaded

Let the figure represent the scale on which the pointer moves and reckon the divisions from the left and call them 1, 2, 3, ...20. Raise the beam and the pointer will oscillate across the scale Observe three consecutive turning points, two to the left and one to the right. Take the mean of the two to the left



and the mean of this and the one to the right. This gives the division at which the pointer will come to rest Suppose the two turning points to the left are 4 and 6, the mean of which is 5, and the turning point to the right is 15, therefore the mean of 5 and 15 is 10. Therefore the pointer will rest at the 10th division counting from the left, *i e* at the middle of the scale

Enter your results on the right-hand page of your practical note book thus —

Date____________

Experiment. To find, by the method of oscillations, the resting point when the pans of the balance are unloaded.

Apparatus A balance

Observations

(1) Turning points

	Left	Right	Resting point.
Mean 5	4 6	15	10

(2) Turning points

	Left	Right	Resting point.
Mean 6 5	5 5 7 5	13 5	10

Result The resting point is at the 10th division

Sensitiveness or sensibility of a balance.

When the balance is loaded or unloaded, a small addition of weight to the weights in the pan will move the pointer through a certain number of scale divisions The number of scale divisions moved through by the pointer will depend, to some extent, on the load in the pans The number of scale divisions moved through by the pointer when a small weight is added to the weights in the pan is called the sensitiveness of the balance and is expressed by saying that the sensitiveness of a balance is so many milligrams per scale division for a given load.

EXPERIMENT No 16 To determine, by the method of oscillations, the sensitiveness of a balance when the pans are unloaded.

First determine the resting point when the pans are unloaded Suppose the resting point is at the

10th division when the pans are unloaded Next place a weight of 10 milligrams in the right-hand pan and determine the resting point Suppose the turning points to the left are 3 and 5 the mean of which is 4 and suppose the turning point to the right is 11. Therefore the resting point is $\frac{4+11}{2} = 7.5$ The resting point when the pans were unloaded was 10. Therefore a weight of 10 milligrams has moved the pointer through $2\frac{1}{2}$ divisions, and therefore the sensitiveness of the balance is 4 milligrams per scale division

Enter your results on the right-hand page of your practical note book thus —

Date__________

Experiment. To find the sensitiveness of a balance when the pans are unloaded

Apparatus A balance, weights

Observations (1) When the pans are unloaded

Turning points

	Left	Right	Resting point
Mean 6 5	$\left\{ \begin{array}{l} 5\cdot5 \\ 7\ 5 \end{array} \right.$	13 5	10

(2) When a weight of 10 milligrams is placed in the right-hand pan

Turning points

	Left	Right	Resting point.
4	$\left\{ \begin{array}{l} 3 \\ 5 \end{array} \right.$	11	7·5

Calculations 10 milligrams have moved the pointer through 2·5 divisions

4 milligrams will move the pointer through 1 division

Result The sensitiveness of the balance when the pans are unloaded is 4 milligrams per scale division

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EXPERIMENT No 17 To find, by the method of oscillations, the weight of a rupee in grams

First find the resting point when the pans are unloaded Suppose the resting point is at the 10th division Having determined the resting point, lower the beam, and place a rupee in the left-hand pan. Place a weight of 20 grams in the right-hand pan **Slightly** raise the beam The first motion of the pointer towards the rupee shows that the 20 gram weight is too much Lower the beam, remove the weight of 20 grams, and in its place put a weight of 10 grams, and slightly raise the beam Suppose the successive steps in weighing are —

20, too great
10, too small
10 + 2, too great
10 + 1, too small
10 + 1 + ·5, too small
10 + 1 + ·5 + ·2, too great
10 + 1 + ·5 + ·1 + ·05, too small
10 + 1 + ·5 + ·1 + ·05 + ·01 approximately correct

Now raise the beam fully and determine the resting point Suppose the turning points to the left are 8 and 8·5 the mean of which is 8·25, and the turning point to the right is 12. Therefore the resting point is 10·125 Therefore the weight of the rupee is 11 66 grams very nearly

Enter your results on the right-hand page of your practical note book thus —

Date ____________

Experiment To find, by the method of oscillations, the weight of a rupee in grams

Apparatus. A balance, weights, a rupee

Observations. (1) When the pans are unloaded.

Turning points			Resting point
	Left	right	
Mean 5	4 6	15	10

(2) When 11·66 grams are placed in the right-hand pan and the rupee in the left hand pan

Turning points			Resting point
	Left	right	
Mean 8·25	8 8 5	12	10·125

Result The weight of the given rupee is 11·66 grams nearly.

(*b*) Method of double weighing or weighing by substitution.

If a balance be not accurate, *i e* when the arms of a balance are of unequal length or the scale pans of

unequal weight, or, where very great accuracy is required, even if the balance be accurate, the method of double weighing is adopted This method is explained below.

Place the object to be weighed in one scale-pan and in the other scale-pan place sand or any other material sufficient to bring the beam to a horizontal position and obtain the resting point. Next remove the object and in its place put known weights sufficient to obtain the same resting point The weight of the object is equal to the weights in the pan.

Distinction between mass and weight.

The mass of a body is the quantity of matter contained in the body and remains the same wherever the body may be taken. The weight of a body is the force or pull with which the earth attracts the body to its centre If the earth were a perfect sphere, all the points on its surface would be equidistant from the centre, and therefore the earth's attraction for the body, *i e*, its weight, would be the same at all points on its surface But as it is not a perfect sphere, the weight of a body is different at different points on its surface If a body be taken into the interior of the earth, *e. g* down a mine, its weight will decrease as some portion of the earth will attract it in the opposite direction If the body be carried further into the interior of the earth, its weight will go on decreasing till at the centre of the earth it will have no weight, because there the body is attracted equally in all

directions by the different parts of the earth If the body be taken up a mountain or higher still in a balloon, its weight will again decrease A body has its maximum weight at the surface of the earth If a piece of iron be weighed by means of a delicate spring balance, its weight may be made to appear greater by holding a strong magnet below it, though its mass remains unaltered. In all this, "weight" means the weight measured by a spring balance and not by a pair of scales which really measures the masses.

EXPERIMENT No. 18. To determine the density of a liquid by weighing a known volume of the liquid.

Take a small beaker and weigh it Fill a burette with the liquid and read the level of the liquid Run some liquid into the beaker from the burette and read the surface of the liquid again Let the volume of the liquid delivered into the beaker be V cubic centimetres Weigh the beaker again, and let M grams be the mass of the liquid run into the beaker Then the density of the liquid $= \frac{M}{V}$ grams per cubic centimetre.

Enter your results on the right-hand page of your practical note book thus —

Date____________

Experiment To determine the density of water by means of a burette

Apparatus A burette, water, a beaker, a balance, weights

Observations

(1) Mass of the empty beaker = 8 grams

(2) Reading of the burette before running off the water, 5 *C C*

(3) Reading of the burette after running off the water, 30 *C C*

(4) Mass of the beaker with water = 32 95 grams

Calculations

Volume of water = 25 *C C*

Mass of water = 24 95 grams

$$\text{Density} = \frac{\text{Mass}}{\text{Volume}} = \frac{24\ 95}{25} = 995$$

Result Density of water = ·995 grams per cubic centimetre

EXPERIMENT No 19. To find the density of a solid heavier than water

Weigh the solid and let its mass be M grams Fill a graduated cylinder with water and read the surface of the water Tilt the cylinder a little and gently slide down the solid into the water Keep the cylinder vertical and again read the surface of the water The difference between the two readings gives the volume of the solid Let the volume of the solid be V cubic centimetres Then the density of the solid is $\frac{M}{V}$ grams per cubic centimetre

Enter your results on the right-hand page of your practical note book thus —

Date____________

Experiment To find the density of iron nails

Apparatus. A graduated cylinder, water, iron nails, a balance, weights

Observations.

(1) Mass of iron nails = 80 85 grams

(2) Reading of the cylinder before dropping in the nails } 26 3 C C.

(3) Reading of the cylinder after dropping in the nails } 36 8 C C.

Calculations. Volume of iron nails = 10·5 C C.

$$\text{Density} = \frac{\text{Mass}}{\text{Volume}} = \frac{80\ 85}{10\ 5} = 7 \cdot 7$$

Result. Density of iron nails = 7·7 grams per cubic centimetre.

EXPERIMENT No. 20. To find the density of a solid lighter than water.

Weigh the solid and let its mass be M grams. Fill a graduated cylinder with water and read the surface of the water. Take a piece of copper so that the solid when fastened to the copper sinks in water. Tilt the cylinder a little, and slowly slide down the combination into the water. Keep the cylinder in a vertical position and read the surface of the water again. The difference between the two readings gives the volume of the combination. Take the combination out of the water and take the reading of the surface of the water Tilt the cylinder a little and slide down the sinker alone into the water. Keep the

cylinder in a vertical position and take the reading of the surface of the water. The difference between the two readings gives the volume of the sinker The difference between the two volumes is the volume of the lighter solid. Let the volume of the lighter solid be V cubic centimetres Then the density of the solid is $\frac{M}{V}$ grams per cubic centimetre

Enter your results on the right-hand page of your practical note book thus —

Date ________

Experiment To find the density of cork

Apparatus A graduated cylinder, water, a cork, a sinker

Observations

(1) Mass of the cork = 1·08 grams

(2) Reading of the cylinder when there is only water in it } 26 3 C C

(3) Reading of the cylinder when the combination is placed in it } 35 8 C C

(4) Reading of the cylinder when there is only water in it } 26 3 C C

(5) Reading of the cylinder when the sinker is placed in it } 31 3 C C

Calculations. Volume of the combination = 9 5 C C

Volume of the sinker = 5 C C

∴ Volume of the cork = 4 5 C C

$$\therefore \text{Density} = \frac{\text{Mass}}{\text{Volume}} = \frac{1\cdot08}{4\ 5} = \ 24$$

Result Density of cork = 24 gram per cubic centimetre

Some important formulas and results.

(1) Circumference of a circle of radius $r = 2\pi r$

(2) Area of a triangle the three sides of which are $a, b, c, = \sqrt{s(s-a)(s-b)(s-c.)}$

where $s = \dfrac{a+b+c}{2}$

(3) Area of a circle of radius $r = \pi r^2$

(4) Volume of a right circular cylinder of radius r and height $h = \pi r^2 h$

(5) Volume of a sphere of radius $r = \frac{4}{3}\pi r^3$

(6) $\pi = 3{\cdot}1416.$

(7) $\frac{1}{\pi} = {\cdot}3183.$

(8) $\pi^2 = 9{\cdot}8696.$

(9) $\sqrt{2} = 1{\cdot}4142.$

(10) $\sqrt{3} = 1{\cdot}7321.$

(11) $\sqrt{5} = 2{\cdot}2361.$

(12) $\sqrt[3]{2} = 1{\cdot}2599.$

(13) $\sqrt[3]{3} = 1{\cdot}4422$

(14) $\sqrt[3]{4} = 1{\cdot}5874.$

(15) $\sqrt[3]{5} = 1{\cdot}71$

EXAMPLES ON CHAPTER I.

(1) A rectangular plate of copper measures 2×2×4 cms, and weighs 143 2 grams Find its density (Ans 8 95 grams per *C C*)

(2) A sphere of silver of density 10·5 grams per *C C* weighs 148·4400 grams Calculate the diameter of the sphere (Ans 3 cms)

(3) An irregular piece of gold of density 19 3 grams per *C C* weighs 239 32 grams Calculate the volume of the solid (Ans 12·4 *C C*)

(4) An aluminium wire 50 metres long weighs 106 029 grams Calculate the diameter of the wire, the density of aluminium being 2 7 grams per *C C* (Ans 1 mm)

(5) The density of mercury is 13 6 grams per *C C* Find the density in pounds per cubic foot, being given that 1 lb =453 59 grams, and 1 foot= 30 48 cms (Ans 849 lbs per cubic foot nearly)

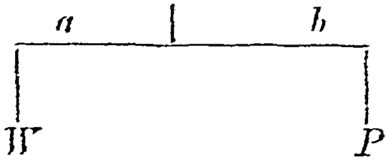
(6) A false balance with unequal arms rests with the beam horizontal when unloaded. A body when hung at the end of the shorter arm appears to weigh *P* grams, and when hung at the end of the longer arm appears to balance *Q* grams. Show that

the true weight W of the body is given by

$$W = \sqrt{P.Q} \text{ grams}$$

Solution.

Let a be length of the shorter arm and b that of the longer arm

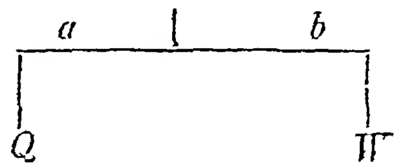


then

$W \times a = P \times b$ ....(1)

and

$Q \times a = W \times b$ ....(2)



Dividing (1) by (2) we have

$$\frac{W}{Q} = \frac{P}{W}$$

$$\text{or } W^2 = PQ$$

$$\therefore W = \sqrt{P.Q}$$

Another method of finding the true weight of a body, namely, by the method of double weighing, has already been indicated in the text.

QUESTIONS ON CHAPTER I.

(Selected from Allahabad University Matriculation Papers)

1 What is the standard of length on the metric system? Name its multiple and sub-multiple divisions, and state the principle on which the system is based. What are its advantages? (1908)

2. Indicate any method of finding the diameter of a sphere (1909)

3. How would you measure the diameter of a cylinder too large to fit into a pair of calipers? (1912)

4. How would you measure the diameter of a very thin wire? (1911)

5 How would you measure the internal diameter of a hollow cylinder? (1910)

6. How would you measure the area of an irregular figure drawn on a sheet of paper? (1911)

7 What is the ratio of the circumference of a circle to its radius? How could you determine this ratio by the aid of a squared millimetre paper and a pair of compasses? (1914)

8 How would you find out the volume of a given irregular solid of unknown density? (1913)

9. Distinguish between the mass and the weight of a body How do these vary as you pass from the earth to the moon? Describe an experiment to illustrate that the weight of a body may be made to appear greater than it actually is, the mass remaining unaltered. (1915, 1908)

10 Describe the principle of the lever, and show how it has been utilised in the construction of a balance. Explain why by means of a crowbar and a block of wood a workman is able to move a heavy log (1908)

11. A body placed in one scale-pan of a false balance appears to weigh 10 lbs, and when placed in the other it weighs 12·1 lbs If the longer arm of the balance be 11 inches in length, find the length of the shorter arm, and the true weight of the body (1908)

12. What is meant by the word density? How would you measure the density of a liquid? (1910) How would you measure the density of water? (1912)

13. How would you determine the density of a given piece of iron? (1914)

CHAPTER II.

HYDROSTATICS.

Relative density. The relative density of a substance is the ratio of the absolute density of the substance to the absolute density of a standard substance If σ be the relative density of a substance, and ρ its absolute density, and ρ_1 the absolute density of the standard substance, then $\sigma = \frac{\rho}{\rho_1}$.

Water at $4°C$ is the standard substance for solids and liquids

Since $\sigma = \frac{\rho}{\rho_1} = \frac{\rho V}{\rho_1 V} = \frac{M}{M_1}$, the relative density of a substance is the ratio of the mass of the substance to the mass of an equal volume of water.

Since masses are measured by weighing them, the relative density of a substance may be defined as the ratio of the weight of the substance to the weight of an equal volume of water The relative density in this case is called the specific gravity.

Whenever relative density or specific gravity is mentioned without stating the standard substance, it is to be understood that the standard substance is water.

Distinction between absolute density and relative density.—The absolute density of a substance is its mass per unit volume and so it depends upon the units of length and mass chosen. By choosing various units of length and mass, the absolute density of the same substance may be expressed by different numbers When the foot is the unit of length and the pound is the unit of mass, the absolute density of water is expressed by the number 62·321 When the centimetre is the unit of length and the gram is the unit of mass, the absolute density of water is expressed by the number 1.

The relative density of a substance is the **ratio** of the absolute density of the substance to the absolute density of water. Whatever may be the units of length and mass chosen, they are involved both in the numerator and the denominator, and so the relative density does not depend upon the units of length and mass.

Since in C G S system the absolute density of water is 1, therefore in that system, the absolute density and the relative density are expressed by the same number.

The absolute density, being the mass per unit volume, is always expressed as so many pounds per cubic foot, or so many grams per cubic centimetre, while the relative density, being a mere ratio, is expressed by an abstract number.

Distinction between relative density and specific gravity The relative density of a substance is the ratio of the **mass** of the substance to the **mass** of an equal volume of water, while its specific gravity is the the ratio of the **weight** of the substance to the **weight** of an equal volume of water Since the weight of a body is exactly proportional to its mass the specific gravity of a substance does not differ from its relative density

Caution. The terms '**density**' and '**relative density**' representing two very distinct ideas should not be used synonymously but must be used strictly in the senses above defined

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EXPERIMENT No 21. To find the specific gravity of a liquid by means of a specific gravity bottle

Weigh the empty bottle, let its weight be W Fill the bottle with water, put in the stopper, taking care that no air bubbles are left in the water and weigh it again Let the weight of the bottle full of water be $W1$. Remove all the water from the bottle, dry it, fill it with the given liquid, put in the stopper and weigh it again Let the weight of the bottle full of the liquid be $W2$,

$\therefore$ weight of the liquid $= W_2 - W$

and weight of the water $= W_1 - W$

$$\therefore \text{ specific gravity } = \frac{W_2 - W}{W_1 - W}.$$

Therefore the specific gravity of the liquid is determined.

Enter your results on the right-hand page of your practical note book thus —

Date____________

Experiment. To determine the specific gravity of alcohol by means of a specific gravity bottle.

Apparatus. A balance, weights, water, alcohol, a specific gravity bottle

Observations.

(1) Weight of the empty bottle = 14 grams.
(2) Weight of the bottle full of water = 39 grams
(3) Weight of the bottle full of alcohol = 34 grams

Calculations

Weight of water filling the bottle = 25 grams.
Weight of alcohol filling the bottle = 20 grams.

Result Specific gravity of alcohol $= \frac{20}{25} = \cdot 8$.

EXPERIMENT No. 22 To find the specific gravity of a solid insoluble in water by means of a specific gravity bottle.

Break the solid into pieces small enough to go into the bottle Weigh these pieces and let their weight be W

Fill the bottle with water. put in the stopper and weigh it Let the weight of the bottle when full of water only be W_1 Open the bottle. put all the pieces of the solid into it, (some water will overflow) replace the stopper and weigh it again. Let the

weight of the bottle full of the solid and the water be W_2. If we suppose x to be the weight of the water which overflowed, then,

$$x + W_2 = W + W_1.$$
$$\therefore \; x = W + W_1 - W_2$$

$\therefore$ the weight of the water displaced is $W + W_1 - W_2$.

$$\therefore \text{ specific gravity } = \frac{W}{W + W_1 - W_2}$$

Therefore the specific gravity of the solid is determined

By this method the specific gravity of a porous solid *e.g.*, chalk may be determined

Enter your results on the right-hand page of your practical note book thus —

Date__________

Experiment. To find the specific gravity of lead balls, by means of a specific gravity bottle

Apparatus A balance, weights, a specific gravity bottle, water, lead balls

Observations

(1) Weight of lead balls = 11 3 grams

(2) Weight of bottle full of water only = 39 grams

(3) Weight of bottle full of lead balls and water = 49 3 grams

Calculations

Let x be the weight of water overflowed

$x + 49 \; 3 = 11 \; 3 + 39 = 50 \; 3$

$x = 1$

Weight of water overflowed = 1 gram

Result. Specific gravity of lead $= \frac{11 \cdot 3}{1} = 11 \cdot 3$

EXPERIMENT No. 23. To find the specific gravity of a solid soluble in water by means of a specific gravity bottle.

Break the solid into pieces small enough to go into the bottle. Weigh these pieces, and let their weight be W. Fill the bottle with any liquid in which the solid is insoluble, (in the case of salt or sugar, alcohol is a suitable liquid) put in the stopper, and weigh it Let the weight of the bottle, when full of this liquid only, be W_1 Open the bottle, put all the pieces of the solid into it (some liquid will overflow), insert the stopper and weigh it again. Let the weight of the bottle full of the solid and the liquid be W_2. If we suppose X to be the weight of the liquid which overflowed, then

$$X + W_2 = W + W_1.$$

$$\therefore X = W + W_1 - W_2$$

$\therefore$ the weight of the liquid displaced is $W + W_1 - W_2$.
$\therefore$ specific gravity

$$= \frac{\text{weight of the solid}}{\text{weight of an equal volume of water}}$$

$$= \frac{\text{weight of the solid}}{\text{weight of an equal volume of the liquid}}$$

$$\times \frac{\text{weight of an equal volume of the liquid}}{\text{weight of an equal volume of water}}$$

$= \dfrac{W}{W + W_1 - W_2} \times \sigma$, where σ is the specific gravity of the liquid.

Therefore the specific gravity of the solid is determined.

N. B.—In the case of sodium or potassium, kerosine oil is used.

Enter your results on the right-hand page of your practical note book thus :—

Date______________

Experiment. To find the specific gravity of sugar by means of a specific gravity bottle.

Apparatus. A balance, weights, a specific gravity bottle, alcohol, and sugar.

Observations.

(1)	Weight of sugar	= 6 grams
(2)	Weight of bottle full of alcohol	= 34 grams
(3)	Weight of bottle full of sugar and alcohol	= 37 grams

Calculations.

Let x be the weight of alcohol overflowed.

$$x + 37 = 6 + 34 = 40$$
$$x = 40 - 37 = 3$$

weight of alcohol overflowed = 3 grams.

density of sugar relative to alcohol $= \frac{6}{3} = 2$,

and since the relative density of alcohol is ·8,

density of sugar relative to water $= 2 \times \cdot 8 = 1 \cdot 6$.

Result. Specific gravity of sugar $= 1 \cdot 6$.

PRINCIPLE OF ARCHIMEDES

Archimedes' Principle. A body wholly immersed in a liquid loses a part of its weight equal to the weight of the liquid displaced If W be the weight of a body in air, and W_1 be its weight in a liquid, then, by Archimedes' principle, the weight of an equal volume of the liquid, that is, the weight of the liquid displaced by the body is equal to $W - W_1$.

Proof of Archimedes' principle. The Principle of Archimedes may be proved by the following experiment.

Take two cylinders—the one a hollow cylinder

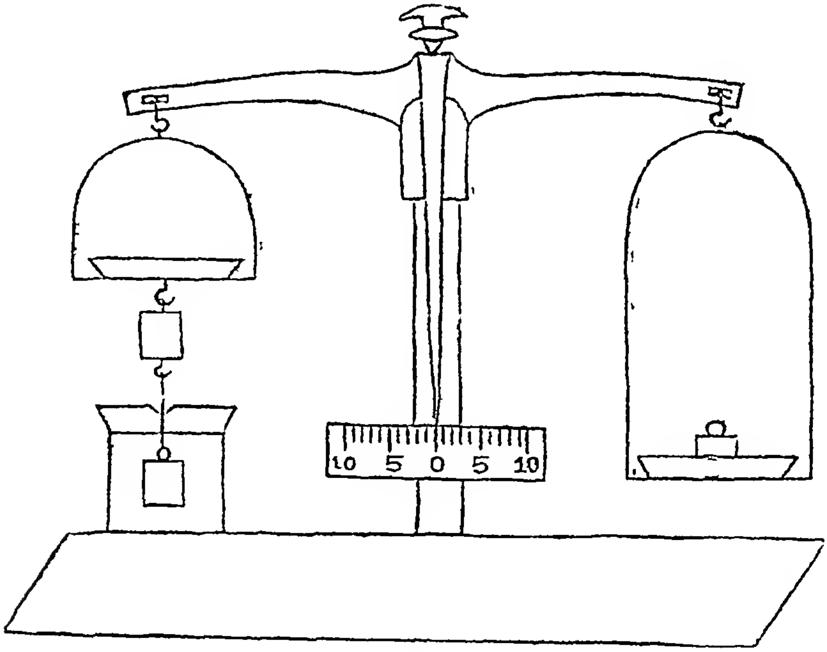


Fig 12

and the other a solid cylinder which exactly fits into the hollow cylinder. Suspend the hollow cylinder

from the shorter pan of a hydrostatic balance and underneath suspend the solid cylinder by means of a thread Place sufficient weights in the other pan to bring the beam to a horizontal position. Place under the cylinders a beaker of water, and raise that beaker so that the solid cylinder is completely immersed in the water. The solid cylinder will lose weight and the beam of the balance will be inclined. Carefully fill the hollow cylinder with water by means of a pipette and when it is quite full, the beam will again be horizontal This shows that the loss of weight is equal to a mass of water whose volume is equal to the volume of the solid cylinder which is immersed

---

EXPERIMENT No 24 To find the specific gravity of a solid heavier than water and insoluble in it by the principle of Archimedes

Weigh the solid in air Let its weight in air be W

Weigh the solid in water. Let its weight in water be W_1.

$\therefore$ The weight of the water displaced $= W - W_1$.

$$\therefore \text{ Specific gravity of the solid } = \frac{W}{W - W_1}.$$

Therefore the specific gravity of the solid is determined.

Enter your results on the right-hand page of your practical note book thus —

Date ____________

Experiment To find the specific gravity of copper by the principle of Archimedes.

Apparatus A hydrostatic balance, weights, a piece of copper, a beaker containing water, a piece of thread

Observations (1) Weight of copper in air $= 17 \cdot 8$ grams.

(2) Weight of copper in water $= 15 \cdot 8$ grams.

Calculation Weight of water displaced by copper $= 2$ grams.

Result Specific gravity of copper $= \dfrac{17 \cdot 8}{2} = 8 \cdot 9$.

EXPERIMENT No 25 To find the specific gravity of a solid soluble in water by the principle of Archimedes.

Weigh the solid in air, let its weight be W. Weigh the solid in a liquid in which it is insoluble (for example salt in alcohol), and let its weight in the liquid be W_1.

$\therefore$ Weight of the liquid displaced $= W - W_1$.

$\therefore$ Specific gravity of the solid

$$= \frac{\text{Weight of the solid in air}}{\text{Weight of an equal volume of water}}$$

$$= \frac{\text{Weight of the solid in air}}{\text{Weight of an equal volume of the liquid}} \times \frac{\text{Weight of an equal volume of the liquid}}{\text{Weight of an equal volume of water}}$$

$= \dfrac{W}{W - W_1} \times \sigma$, where σ is the specific gravity of the liquid

Therefore the specific gravity of the solid is determined.

Enter your results on the right-hand page of your practical note book thus —

Date__________

Experiment To find the specific gravity of rock salt by the principle of Archimedes

Apparatus A hydrostatic balance, weights, a piece of salt, alcohol, a piece of thread

Observations (1) Weight of salt in air = 12 grams

(2) Weight of salt in alcohol = 7 grams

Calculations Weight of alcohol displaced by salt = 5 grams.

∴ Density of salt relative to alcohol $= \frac{12}{5} = 2.4$

Since the density of alcohol relative to water is .8,

∴ Density of salt relative to water $= 2.4 \times .8 = 1.92$

Result Specific gravity of salt = 1.92

EXPERIMENT No 26 To find the specific gravity of an insoluble solid lighter than water by the principle of Archimedes

Weigh the solid in air Let its weight in air be W Weigh a sinker in water Let the weight of the sinker in water be W_1

Weigh the solid and the sinker combined in water, and let the weight of combination in water be W_2. If we suppose X to be the weight of the sinker in air, then $W + X$ is the weight of the combination in air, and W_2 is the weight of the combination in water ;

$\therefore W+X-W_2$ is the weight of the water displaced by the combination

And $X-W_1$ is the weight of water displaced by the sinker alone.

Therefore $(W+X-W_2)-(X-W_1)=W+W_1-W_2$ = the weight of water displaced by the solid

$$\therefore \text{Specific gravity of the solid} = \frac{W}{W+W_1-W_2}$$

Therefore the specific gravity of the solid is determined.

Enter your results on the right-hand page of your practical note book thus —

Date____________

Experiment To find the specific gravity of bees wax by Archimedes' principle

Apparatus. A hydrostatic balance, weights, a beaker containing water, wax a piece of thread.

Observations (1) Weight of wax in air = 4 8 grams.
(2) Weight of sinker in water = 15 ·8 grams.
(3) Weight of sinker and wax together in water = 15 6 grams.

Calculations

Suppose x to be the weight of the sinker in air

$\therefore x-4$ 8 is the weight of the combination in air,
and 15 6 is the weight of the combination in water,

$\therefore x+4$ 8-15 6$=x-10$ 8 is the weight of water displaced by the combination

And $x-15\ 8$ is the weight of water displaced by the sinker alone

∴ The weight of the water displaced by the wax $= (x-10\ 8) - (x-15\ 8) = 5$ grams

Specific gravity of wax $= \frac{4\ 8}{5} = \ 96$

Result. Specific gravity of wax $= \cdot 96$

EXPERIMENT No 27. To find the specific gravity of a liquid by the Principle of Archimedes.

Take a solid which is insoluble in the given liquid and weigh it in air, let its weight in air be W Weigh the solid in water and let its weight in water be W_1 Weigh the solid in the given liquid and let its weight in the given liquid be W_2

∴ weight of the water displaced by the solid $= W - W_1$,

and weight of the liquid displaced by the solid $= W - W_2$

∴ Specific gravity of the liquid $= \dfrac{W - W_2}{W - W_1}$

Therefore the specific gravity of the liquid is determined.

Enter your results on the right-hand page of your practical note book thus —

Date____________

Experiment To find the specific gravity of Kerosine oil by the principle of Archimedes

Apparatus A Hydrostatic balance, weights, kerosine oil, water, a piece of thread, a piece of copper

Observations

(1) Weight of copper in air = 17·8 grams
(2) Weight of copper in water = 15·8 grams
(3) Weight of copper in kerosine oil = 16·12 grams

Calculations

Weight of water displaced by copper = 2 grams
Weight of kerosine oil displaced by copper = 1·68 grams.

Result Specific gravity of kerosine oil $= \dfrac{1 \cdot 68}{2} = \cdot 84$

N B—In the case of sulphuric acid, a piece of platinum, or glass is employed

---

EXPERIMENT No. 28 To compare the densities of two liquids, which do not mix, by a U-tube.

Mount a U-tube, having a uniform bore, vertically on a stand. Pour in the denser of the two liquids first. Then pour the lighter liquid through one of the legs. The surface where the two liquids meet is called the common surface. Let *L* be the area of the cross section of the tube. Let *A B* be the column of the denser liquid above the level of the common surface, and let *C D* be the column of the lighter liquid above the common surface. Let h and h_1 be the heights of the columns *AB* and *CD*. Let W and W_1 be the weights of the liquids in the columns *AB* and *CD*, M and M_1 their masses,

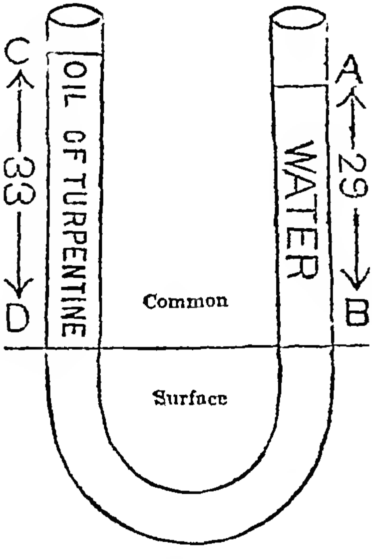


Fig 13

V and V_1 their volumes, and let ρ and ρ_1 be the absolute densities of the liquids. Let P be the pressure of the air. Since the common surface is stationary, the weight of the liquid in column $AB + P$ = the weight of the liquid in column $CD + P$. $W + P = W_1 + P$, or $W = W_1$, but the weights of bodies are exactly proportional to their masses,

$$\therefore M = M_1$$

$$\text{but } M = V\rho, \text{ and } M_1 = V_1 \rho_1,$$

$$\text{and } V = h\,L \text{ and } V_1 = h_1\,L$$

$$\therefore M = h\rho\,L, \text{ and } M_1 = h_1\,\rho_1\,L.$$

$$\therefore h\rho\,L = h_1\,\rho_1\,L.$$

$$\therefore h\rho = h_1\,\rho_1,$$

$$\text{or } \frac{\rho}{\rho_1} = \frac{h_1}{h}.$$

That is, the densities of the two liquids are inversely proportional to their heights above the common surface.

Enter your results on the right-hand page of your practical note book thus:—

Date____________

Experiment. To compare the densities of oil of turpentine and water by means of a U tube.

Apparatus. A U-tube, water, oil of turpentine, a scale.

Observations.

(1) Height of the water column above the level of the common surface = 29 *mm*.

(2) Height of the oil column above the common surface = 33 *mm*.

Result. Density of turpentine oil relative to water

$$= \frac{29}{33} = .87.$$

EXPERIMENT No. 29. To compare the densities of two liquids which mix by means of a U-tube.

Mount a long U-tube, having a uniform bore, vertically on a stand. Introduce some mercury into the tube, and read the level of the mercury, if the tube be graduated. If the tube be not graduated, paste a narrow strip of paper round one limb, so that the edge of the paper is exactly on the same level with the surface of the mercury. Into one limb pour the lighter of the two liquids, but not so much as to drive the mercury out of the bend. Then pour the denser

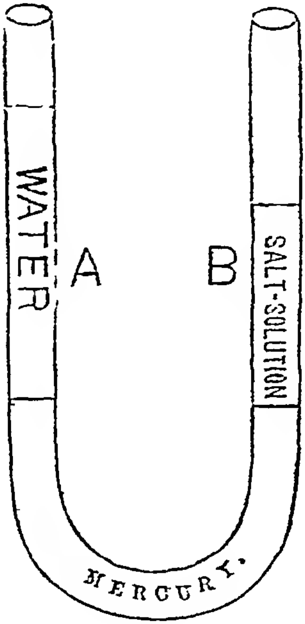


Fig 14

liquid into the other limb, till the mercury returns to its original level. Measure the heights of the columns of the two liquids above the surface of the mercury. Call the column of the lighter liquid A, and that of the denser liquid B. Let h and h_1 be their heights, W and W_1 their weights, M and M_1 their masses, V and V_1 their volumes, and let ρ and ρ_1 be the densities of the two liquids. Let L be the area of the cross-section of the tube. Since the mercury stands at the same height in the two tubes, the pressures on the surfaces of mercury in the two columns must be equal.

The pressure on the surface of the mercury in one tube is $W + P$, where P is the pressure of the air, and that in the other tube is $W_1 + P$.

$$\therefore\ W + P = W_1 + P.$$
$$\therefore\ W = W_1$$

But weights of bodies are exactly proportional to their masses,

$$\therefore\ M = M_1$$
$$\therefore\ V\rho = V_1\,\rho_1$$

but $V = L\,h$, and $V_1 = L\,h_1$

$$\therefore\ L\,h\,\rho = L\,h_1\,\rho_1,$$
$$\text{or } h\,\rho = h_1\,\rho_1.$$
$$\therefore\ \frac{\rho}{\rho_1} = \frac{h_1}{h}$$

That is, the densities of the two liquids are inversely proportional to their heights above the surface of the mercury

Enter your results on the right-hand page of your practical note book thus —

Date____________

Experiment To compare the densities of water and a given solution of salt by means of a U tube.

Apparatus A U-tube, water, salt solution, mercury, and a scale

Observations. (1) Height of water column above the surface of mercury = 33 *mm*

(2) Height of the solution column above the surface of mercury = 22 *mm*

Result. Density of the salt solution relative to water =

$$\frac{16\ 5}{11} = 1\ 5$$

BAROMETER.

Take a glass tube closed at one end about 84 centimetres long, and 1·5 centimetres in diameter. Fill it completely with mercury, and close the open end with the thumb. Invert the tube, place the open end in mercury in a vessel, and remove the thumb The tube being vertical, the column of the mercury sinks, and stands at a height of about 76 centimetres from the surface of the mercury in the basin, leaving a vacuum at the upper end This vacuum is called Torricelli's vacuum, because this experiment was first tried by Torricelli in 1643. There is no air in contact with the surface of the mercury in the tube, and therefore there is no pressure on it But the air presses the mercury in the basin, and this pressure supports the column of the mercury in the tube If the pressure of the air increases, the column is forced up, if it decreases, the column descends The pressure of the air can, therefore, be measured by the height of the column of the mercury in the tube.

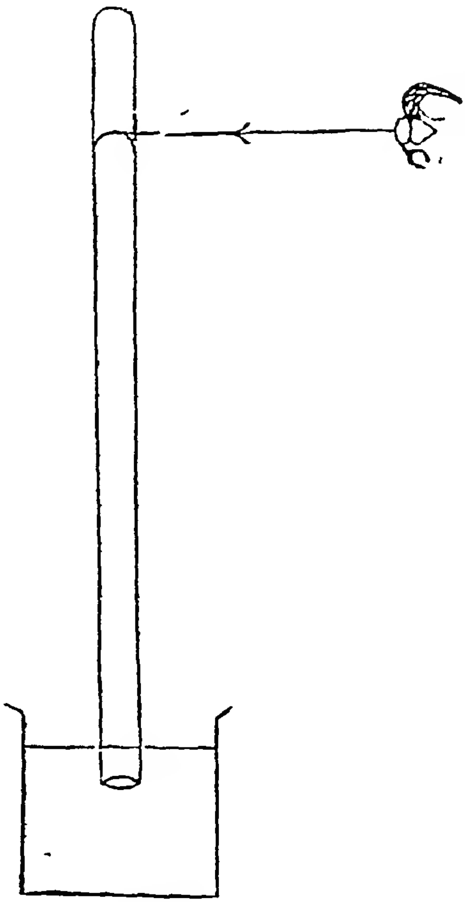


Fig 15

A barometer is an instrument for measuring the pressure of the atmosphere. The commonest kind of barometer consists of a straight glass tube closed at one end, about 84 centimetres long and 1·5 centimetres in diameter, filled with mercury and dipping into mercury contained in a cistern. This tube is enclosed in a brass tube on which is engraved a scale in millimetres, the zero of the scale coinciding with the surface of the mercury in the cistern. The scale is graduated between 68 and 84 centimetres, because the pressure of the atmosphere is never outside these limits. A vernier, capable of sliding along the scale, is also attached to the tube. 20 divisions of the vernier are equal to 19 divisions of the scale. One division of the scale is one millimetre, and therefore one division of the vernier is $\frac{19}{20}$ of a millimetre. The difference, therefore, between one division of the scale and one division of the vernier is $\frac{1}{20}$ *mm* = ·05 *mm*. Therefore the height of the barometer can be measured accurately to ·05 *mm*. For the sake of clearness, the divisions on the main scale and the vernier are shown magnified.

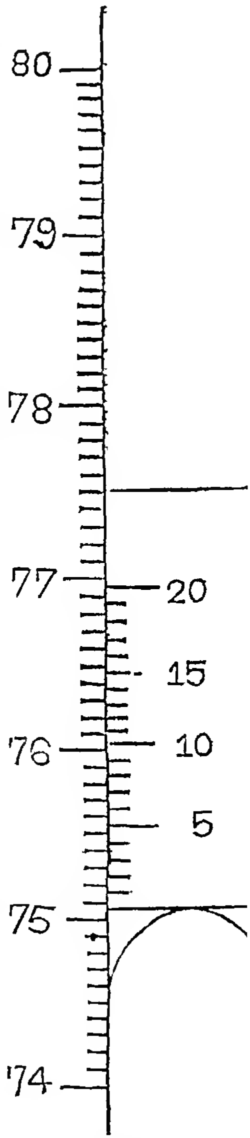


Fig 16

If a barometer be carried up a mountain, the column of mercury must descend, because some of the air, which formerly supported it, is left below.

The barometer is fixed in a vertical position, and the vernier is moved till the zero of the vernier is on a level with the common surface of the mercury column, a reading is then taken, keeping the line of sight horizontal.

EXPERIMENT No. 30. To read the barometer.

The barometer will be already found to be fixed in a vertical position in the laboratory Move the vernier till the zero of the vernier coincides with the convex surface of the mercury in the tube. Take the reading Suppose that when the zero of the vernier is on a level with the convex surface of the mercury, the zero of the vernier lies between 750 and 751 *mm*, and the 12th division of the vernier coincides with a division of the scale The scale of the barometer is divided into millimetres 20 divisions of the vernier are equal to 19 divisions of the scale. Therefore one division of the vernier is $\frac{19}{20}$ *mm* Therefore the difference between one division of the scale and one division of the vernier is $\frac{1}{20}$ *mm* = $\cdot 05$ *mm*. Since the 12th division of the vernier coincides with a division on the scale, therefore the difference between the zero division of the vernier and the 750th

division of the scale is the difference between 12 divisions of the scale, namely, from 750 to 762 and 12 divisions of the vernier, and this is equal to $12 \times \cdot 05 = \cdot 6$ *mm* Therefore the reading of the barometer is $750 + \cdot 6 = 750 \cdot 6$ *mms*

Enter your results on the right-hand page of your practical note book thus —

Date__________

Experiment To read the barometer

Apparatus A barometer

Observation When the zero of the vernier is on a level with the convex surface of the mercury, the zero of the vernier lies between 750 and 751 *mm* and the 12th division of the vernier coincides with a division on the scale

Calculations.

The scale of the barometer is divided into millimetres

20 divisions of the vernier = 19 divisions of the scale

$\therefore$ 1 division of the vernier $= \frac{19}{20}$ *mm*,

$\therefore$ the difference between one division of the scale and one division of the vernier $= \frac{1}{20}$ *mm* $= \cdot 05$ *mm*,

$\therefore$ the difference between 12 divisions of the scale and 12 divisions of the vernier is $12 \times \cdot 05 = \cdot 6$ *mm*,

$\therefore$ the reading is $750 + \cdot 6 = 750 \cdot 6$ *mm*

Result. The height of the barometer $= 750 \cdot 6$ *mms*

Table of specific gravities.

Solids

Aluminium ...	2 7	Marble... ...	2·7
Brass	8 4	Nickel	8·57
Copper	8 95	Platinum ...	21·5
Cork	·24	Rock Salt ...	1·9
Gold	19·3	Silver	10 57
Iron	7 76	Tin	7·3
Ivory	1·92	Wax (bees) ...	·96
Lead	11·4	Zinc	7·2

Liquids

Alcohol ...	·8	Nitric acid ...	1·5
Glycerine ...	1·26	Olive oil ...	915
Mercury ...	13 6	Petroleum ...	·86
Milk	1·03	Sulphuric acid	1·85
Turpentine oil	87		

EXAMPLES ON CHAPTER II.

(1) A specific gravity bottle completely full of water weighs 39 grams, and when 11 3 grams of a certain solid have been introduced, it weighs 49·3 grams Find the specific gravity of the solid (Ans 11·3)

(2) A piece of copper of specific gravity 8 9 weighs 15 8 grams in water, find its weight in air. (Ans 17·8 grams)

(3) A piece of wax weighs 4·8 grams in air; when a piece of copper is attached to the wax, the combination weighs 15·6 grams in water, if the weight of the copper in water be 15 8 grams, find the specific gravity of wax (Ans ·96)

(4) A piece of marble of specific gravity 2·7 weighs 49·3 grams in water, and 53 07 grams in oil of turpentine. Find the specific gravity of the oil. (Ans. 87)

(5) Find the specific gravity of sulphuric acid if a piece of platinum of specific gravity 21·5 weighs 43 grams in air, and 39 3 grams in sulphuric acid. (Ans 1·85)

(6) A piece of copper weighs 17·8 grams in air, 15 8 grams in water, and 16 12 grams in kerosine oil Find the specific gravity of kerosine oil (Ans ·84)

(7) The lower portion of a U-tube contains mercury How many centimetres of water must be poured into one leg to raise the mercury 2·5 centimetres in the other, the specific gravity of mercury being 13 6? (Ans 6 8 *cms*)

(8) The legs of a U-tube are each 12 *cms* long Water is poured into the U-tube till it is half full As much oil (specific gravity ·8) as possible is then poured into one of the legs Determine the height of the oil column (Ans 10 *cms*)

QUESTIONS ON CHAPTER II.

(Selected from Allahabad University Matriculation Papers)

1 Distinguish between absolute and relative density, and prove that the former depends upon the units of length and mass, while the latter does not. Show also that on the metric system, the two densities are expressed by the same number. (1908) Se

2 Explain the terms 'relative density,' 'specific gravity' How would you determine the density of a liquid relative to water at a given temperature (1915) See

3 Describe any method of finding the relative densities of two liquids A U-tube of uniform bore about half filled with water, is fixed in a vertical position, and oil (of density ·8) is poured into one limb till the water rises 4 *cms*, in the other What mass of oil was poured into the tube? (1909)

4 How would you determine the density of sulphuric acid relative to water at a given temperature? (1911)

5. You are given a balance, a brass ball, and two liquids, how could you compare the densities of the two liquids? (1915)

6 How can the relative density of iron nails be determined? (1909)

7 Some iron nails weigh 3 grams in air When a density bottle filled with water is placed beside the nails on the balance pan the weight of the nails and the bottle is 151 grams The nails are then put into the bottle, and the bottle and nails then weigh 112 grams Find the density of the iron nails. (1910)

8 How would you test a coin to see if it is pure gold? (1911)

9 How would you determine the specific gravity of common salt? (1914)

10 Describe the construction and use of a barometer How does the length of the column of mercury in a barometer change with the altitude above the sea level? Give reasons for your answer. (1908)

CHAPTER III.

HEAT.

Temperature. The temperature of a body is that condition of the body on which its power to communicate heat to, or to receive heat from, another body depends

A **thermometer** is an instrument used to measure and to indicate temperature

Construction of a mercury thermometer.

(*a*) **Filling the thermometer.** A glass tube is taken, which has a fine uniform bore and a bulb at one end and a funnel at the other end Mercury is placed in the funnel As the bore is fine, the mercury will not run to the bulb The bulb is gently heated The air inside expands, and some of it escapes through the liquid The bulb is then allowed to cool The air inside contracts, and its pressure becomes less than the pressure of the air outside, and so some mercury is forced into the bulb. Thus, by alternately heating and cooling, the bulb and the tube are filled with mercury. The mercury is then boiled and the mercury vapour as it escapes carries with it any remaining air and moisture When the bulb and the tube are full of mercury

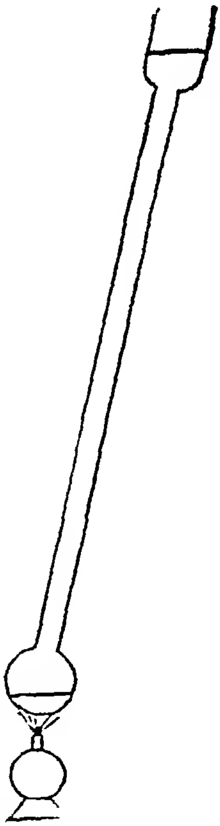


Fig 17

and its vapour, the tube is heated near the funnel, the funnel is removed, and the end is hermetically sealed by fusing the glass On cooling, the mercury vapour condenses, the whole contents of the bulb contract, and a vacuum is left at the upper end of the tube

(*b*) **Fixed points of a thermometer.** It has been found that (1) ice melts at a constant temperature, and (2) water boils at another constant temperature if the pressure of the atmosphere be the same These two temperatures, namely, the temperature of melting ice, and the temperature of steam when the barometer reads 760 *mm*, are the fixed points of a thermometer The former is called the **freezing** point, and the latter the **boiling** point

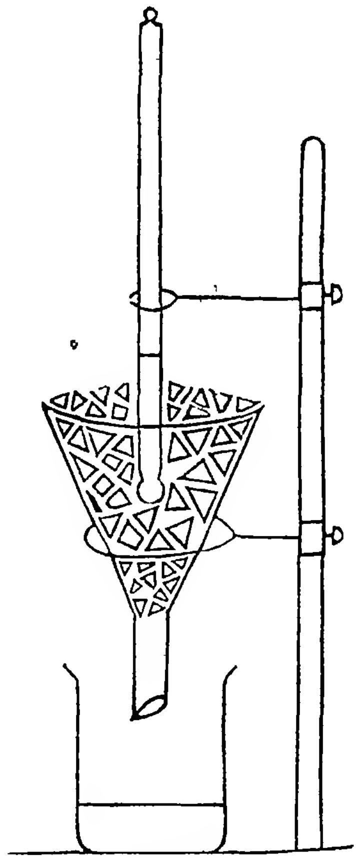


Fig 18

(*c*) **Determination of fixed points (1) Melting point.** The thermometer is placed vertically in a funnel shaped vessel, and the bulb and the lower part of the stem are completely surrounded with melting ice When the mercury has become stationary, its level in marked This is the melting or freezing point It is marked 32° on the Fahrenheit scale, and 0° on the Centigrade and the Reaumur scales

(2) **The boiling point.** The thermometer is then placed vertically in an instrument, called a hypsometer, so that the bulb and the greater portion of the stem are surrounded with steam issuing from boiling water which is boiled in the lower part of the instrument When the level of the mercury has become stationary, a fine mark is made there (A correction is made if the barometer does not read 760 *mm* For correction see Experiment No 32, pages 82 and 83) This is the boiling point It is marked 212° on the Fahrenheit scale, 100° on the Centigrade scale, and 80° on the Reaumur scale

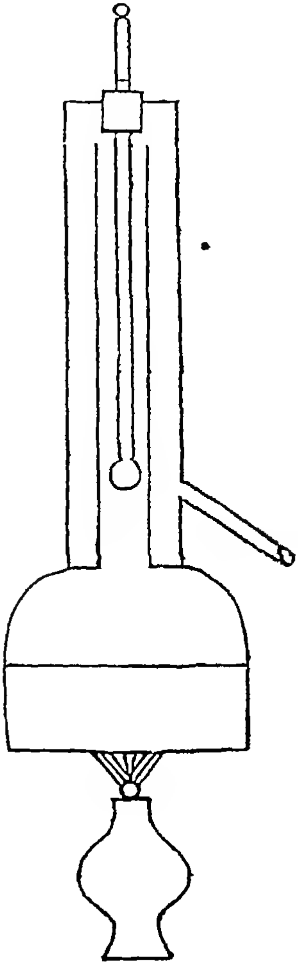


Fig 19

(*d*) **Graduation of thermometer.** The distance between the two fixed points is divided equally into 180 parts on the Fahrenheit scale, 100 parts on the Centigrade scale, and 80 parts on the Reaumur scale. The divisions are continued above the boiling point and below the freezing point.

(*e*) **Comparison of thermometric scales.** Since the distance between the freezing and boiling point is the same on each scale,

∴ 180 divisions on the Fahrenheit scale = 100 divisions on the Centigrade scale = 80 divisions on the Reaumur scale,

or 9 divisions on the Fahrenheit scale = 5 divisions on the Centigrade scale = 4 divisions on the Reaumur scale

If any temperature be denoted by F, C, and R on the three scales respectively,

$$\text{then } C = (F - 32) \times \frac{5}{9} \text{ or } \frac{C}{5} = \frac{F-32}{9},$$

$$\text{and } R = \frac{4}{5} C \therefore \frac{C}{5} = \frac{R}{4},$$

$$\therefore \frac{F-32}{9} = \frac{C}{5} = \frac{R}{4}$$

EXPERIMENT No 31 To determine the error in the zero point of a thermometer, or to test the correctness of its freezing point

Take a funnel and support it in a clamp Take some ice, break it into very small pieces, and wash it with distilled water to remove any salt mixed with it Place a beaker under the funnel to receive the water melted off the ice Put the pieces of ice into the funnel and place the thermometer vertically in the ice so that the whole bulb and the stem up to the freezing point mark are surrounded with the ice When the mercury in the thermometer has become stationary, take the reading, estimating to the tenth of a degree In taking the reading, keep the line of sight horizontal The difference between this reading

and the freezing point marked on the thermometer is the error in the freezing point If the reading be above the freezing point. the correction is negative, if below it. it is positive

Enter your results on the right-hand page of your practical note book thus —

Date____________

Experiment. To test the correctness of the freezing point of a thermometer.

Apparatus. A funnel. some ice, a beaker, a thermometer.

Observations and results.

(1) Centigrade thermometer.

	Freezing point.
Marked	0°.
Observed ...	+0·2°
Correction .	—0·2°

(2) Fahrenheit thermometer.

	Freezing point.
Marked ..	32°.
Observed ..	31·6°
Correction ..	+0·4°

EXPERIMENT No. 32 To test the correctness of the boiling point (100° *C.*) of a thermometer.

Put some water into a flask and fit it with a two-hole cork Through one hole pass an exit tube, and through the other pass the thermometer vertically so that the bulb of the thermometer is about two inches above the level of the water in the flask, and the boiling point mark of the thermometer is just above the cork. Set the water to boil, and when the water is freely boiling, read the thermometer to the tenth of a degree, keeping the line of sight horizontal This is the observed boiling point Read the barometer also.

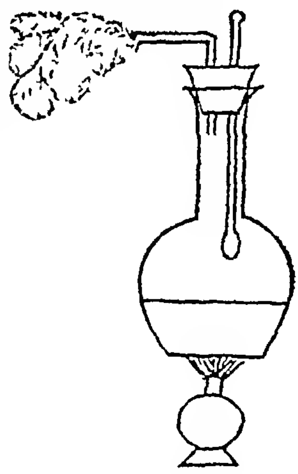


Fig. 20

The boiling point of water is 100° *C.* when the barometer reads 760 *mm* The boiling point of water is increased or decreased 0°.36° *C.* by an increase or decrease of 10 *mm* of pressure. Calculate the boiling point of water for the existing barometric height. From this calculated boiling point subtract the observed reading of the thermometer The difference is the correction The correction is negative if the reading of the thermometer be above the calculated boiling point, and positive if below it.

Enter your results on the right-hand page of your practical note book thus —

Date____________

Experiment. To test the correctness of the boiling point of a Centigrade thermometer

Apparatus A flask fitted with a two-hole cork and an exit tube, a Centigrade thermometer, water, a barometer

Observations. (1) Boiling point of water as indicated by the thermometer, $99 \cdot 5°C$

(2) Height of the barometer at the time of the experiment, 750 *mm*

Calculations Boiling point of water is $100°C$ when the barometer reads 760 *mm*.

Barometer reads 750 *mm* at the time of the expriment,

$\therefore$ the barometric height has fallen 10 *mm* $= 1$ *cm*,

$\therefore$ the boiling point of water must fall $36 \times 1 = 0 \cdot 36°C$,

$\therefore$ the boiling point of water at the existing pressure is $100 - \cdot 36 = 99 \cdot 64°C$

The reading of the thermometer is $99 \cdot 5°C$

$\therefore$ correction is $+0 \cdot 14°C$

Result Correction $= +\ 0 \cdot 14°C$

EXPERIMENT No. 33 To find experimentally the connection between the readings of a Fahrenheit and a Centigrade thermometer and to exhibit the relation by means of a graph.

Take four beakers and place some cold water into each of them Heat some water in a vessel and pour some hot water into each of the beakers. Place the two thermometers side by side successively into each of the beakers and take the readings of the two thermometers simultaneously

On a sheet of curve paper mark two straight lines $X_1 \, O \, X$ and $Y_1 \, O \, Y$ at right angles to each other, $X_1 \, O \, X$ horizontal, and $Y_1 \, O \, Y$ vertical. On $O \, X$

mark off OM to represent a Fahrenheit reading and

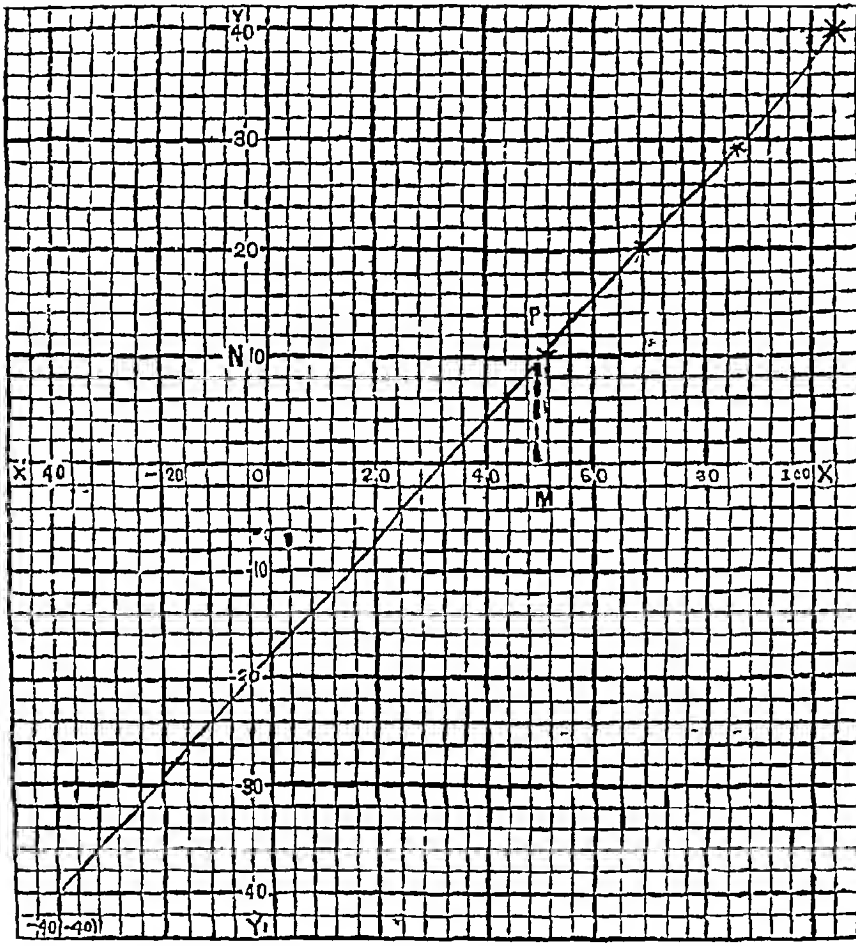


Fig 21.

on OY mark off ON to represent the corresponding Centigrade reading Through M and N draw straight lines MP and NP parallel to OY and OX respectively, intersecting in P Thus a point P is obtained whose abscissa represents a Fahrenheit reading and whose ordinate represents the corresponding Centigrade reading Thus, by graduating OX in Fahren-

heit degrees and OY in Centigrade degrees, plot the different points Unite these points by a curve, and the curve passing through these points is the graph. If the readings be accurately taken, this curve will be found to be a straight line not passing through the origin.

[*It should be noted that the curve passes through the point* $-40°$, $-40°$, *which shows that* $-40°$ *is the temperature represented by the same number on the two thermometers*]

Enter your results on the right-hand page of your practical note book thus —

Date_____________

Experiment To find the connection between the readings of a Fahrenheit and a Centigrade thermometer and to represent the relation by means of a graph

Apparatus. Four beakers containing cold water, some hot water, one Fahrenheit thermometer, one Centigrade thermometer, a sheet of curve paper

Observations and result

F	C
50°	10°
68°	20°
86°	30
104°	40°

EXPANSION.

As a rule bodies expand when heated When the expansion of a body is considered in **length**, the expansion is said to be **linear**, when the expansion of a body is considered in **area**. the expansion is said

to be **superficial**; and when the expansion of a body is considered in **volume**, the expansion is said to be **cubical**

Coefficient of linear expansion. The coefficient of linear expansion of a substance is the increase in length when one unit length of that substance is heated 1°*C* If a rod of copper 1 *cm* long be heated through 1°*C*, it is found that it increases by ·000017 *cm.*, therefore the coefficient of linear expansion of copper is ·000017 The coefficient of linear expansion of a solid is a small quantity, indeed so small that its square and higher powers may be neglected without appreciable error.

To show that $l_t = l_o(1 + \beta t)$, where l_o is the length of a rod at 0°*C*, l_t is its length at t°*C*., β is the coefficient of linear expansion of the substance and t is the change of temperature from 0°*C*. to t°*C*.

When 1 unit length is heated 1°*C*, the increase in length is β,

$\therefore$ when 1 unit length is heated t°*C*, the increase in length is βt,

$\therefore$ when l_o units length are heated t°*C*, the increase in length is $l_o \beta t$,

$\therefore$ the increase in length is $l_o \beta t$,

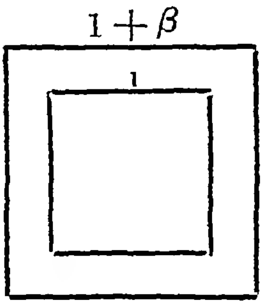
$\therefore$ the total length at t°*C* is $l_o + l_o \beta t = l_o(1+\beta t)$,

or $l_t = l_o(1 + \beta t)$

Coefficient of superficial expansion The coefficient of superficial expansion of a substance is the increase in area when 1 unit area of that substance is heated 1°*C*

To show that the coefficient of superficial expansion of a substance is twice the coefficient of linear expansion.

Take a square plate each side of which is 1 *cm.* at 0°*C*. The area of the plate at 0°*C* is, therefore, 1 sq. *cm* Heat the plate to 1°*C*. Each side will increase by β. Therefore the area of the plate at 1°*C*. is $(1+\beta)^2 = 1+2\beta$, neglecting β^2 which is a very small quantity. Therefore the increase in area when 1 unit area is heated 1°*C*. is 2β, or $\gamma = 2\beta$, where γ is the coefficient of superficial expansion.



To show that $S_t = S_0 (1 + \gamma t)$, where S_0 is the area at 0°*C*., S_t is the area at t°*C*, γ is the coefficient of superficial expansion, and t is the change of temperature from 0° *C*. to t°*C*.

When 1 unit area is heated 1°*C*, the increase in area is γ,

∴ when 1 unit area is heated t°*C*., the increase in area is γt,

∴ when S_0 units area are heated t°*C*, the increase in area is $S_0 \gamma t$,

∴ the increase in area is $S_0 \gamma t$,

∴ the total area at t°*C*. is $S_0 + S_0 \gamma t$,

or $S_t = S_0 (1 + \gamma t)$.

Coefficient of cubical expansion. The coefficient of cubical expansion of a substance is the increase in volume when 1 unit volume of that substance is heated $1°C$

To show that the coefficient of cubical expansion of a substance is thrice the coefficient of linear expansion of that substance.

Take a cube each side of which is 1 *cm* at $0°C$ The volume of the cube at $0°C$ is, therefore, 1 C C Heat the cube to $1°C$ Each side will increase by β. The volume of the cube at $1°C$ is, therefore, $(1+\beta)^3 = 1 + 3\beta$, neglecting $\beta^3 + 3\beta^2$ which is very small. Therefore the increase in volume when 1 unit volume is heated $1°C$. is 3β or $\delta = 3\beta$, where δ is the coefficient of cubical expansion.

To show that $V_t = V_o(1+\delta t)$, where V_o is the volume at $0°C$, V_t is the volume at $t°C$, δ is the coefficient of cubical expansion, and t is the change of temperature from $0°C$. to $t°C$.

When 1 unit volume is heated $1°C$, the increase in volume is δ,

$\therefore$ when 1 unit volume is heated $t°C$., the increase in volume is δt,

$\therefore$ when V_o units volume are heated $t°C$., the increase in volume is $V_o\,\delta t$,

$\therefore$ the increase in volume is $V_o\,\delta t$,

$\therefore$ the total volume at $t°C$ is $V_o + V_o\,\delta t = V_o(1+\delta t)$, or $V_t = V_o(1+\delta t)$

Absolute and Apparent expansion. When a liquid is heated, it expands, and the vessel containing the liquid also expands In the expansion of a liquid, the visible increase of the volume which is the excess of the expansion of the liquid over the expansion of the containing vessel is called the **apparent** expansion of the liquid, while the actual increase in its volume which is equal to the sum of its apparent expansion and the expansion of the containing vessel is called the **real** or **absolute** expansion of the liquid

Hope's experiment to show that water has its maximum density at 4°*C.*

Description of the apparatus. Hope's apparatus consists of a cylinder of metal about 1 foot high

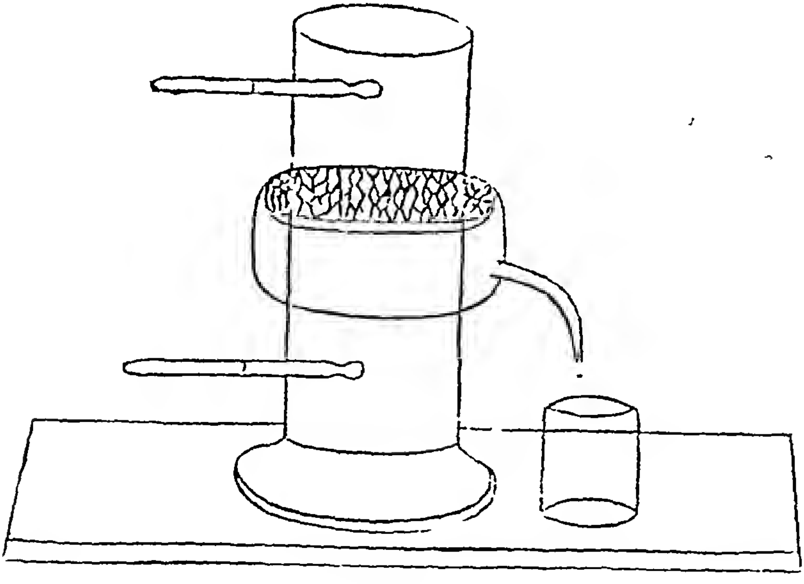


Fig 22

and 4 inches in diameter and surrounded about its middle part by a jacket to hold ice and salt From

the jacket passes a small outlet to allow the water melted off the ice to escape Two thermometers pass through corks which are fitted into short tubes which are fixed into the sides of the cylinder above and below the jacket The thermometers are inserted in such a way that when the bulbs are in the middle of the cylinder, all the graduations are outside

Experiment. This experiment is performed in a cool place The cylinder is filled with water which has been cooled down to 6°*C* Pounded salt and ice is placed in the jacket. As the water is cooled by the ice in the jacket, it becomes denser and sinks, warmer water which is lighter rises from the bottom, is cooled and sinks in turn, so the lower thermometer shows a gradual fall of temperature, while the upper thermometer remains stationary At 4°*C*, the lower thermometer ceases to fall This shows that the further cooling of water by the ice does not make it denser The water in the middle is now cooled below 4°*C*, expands, becomes lighter and rises Denser water from the top flows down, is cooled and rises Thus the whole water above the jacket is cooled The upper thermometer now begins to fall till it reaches 0°*C* The lower thermometer still continues to show 4°*C*. This experiment shows that water at 4°*C* is denser than at any other temperature higher or lower.

Peculiarity in the expansion of water. If water at 0°*C* be heated, instead of expanding, it contracts, and continues to do so till the temperature

rises to $4^{\circ}C$. If further heating be continued, it will expand This peculiarity or anomaly in the expansion of water is an exception to the general rule that bodies expand when heated.

QUANTITY OF HEAT.

Heat which changes the temperature of a body is called **sensible heat**

The **unit of heat** or the **thermal unit** is the amount of heat required to raise the temperature of one unit mass of water through one degree

The **British thermal unit** is the amount of heat required to raise the temperature of one pound of water through one degree Fahrenheit

The **French thermal unit** or the **calorie** is the amount of heat required to raise the temperature of one gram of water through one degree Centigrade The calorie is the unit of heat employed in the laboratory

The **Specific heat** of a substance is the number of calories required to raise the temperature of one gram of the substance through one degree Centigrade

The **thermal capacity** of a body is the number of calories required to raise the temperature of the total mass of the body through one degree Centigrade If M be the mass of the body, and S its specific heat, and C its thermal capacity, then $C = MS$.

// The **water equivalent** of a body is the number of grams of water the temperature of which will be raised through one degree Centigrade by the amount of heat required to raise the temperature of the body through one degree Centigrade If M be the mass of the body, S its specific heat, and w the water equivalent of the body, then $w = MS$

A **Calorimeter** consists essentially of a cylindrical vessel of thin copper To prevent the loss of heat to the air, the outside of this vessel is polished and it is surrounded by a similar but larger copper vessel in which it is suspended by silk threads The inside of this larger vessel is also polished, and the larger vessel is placed inside a wooden box and wool is lightly packed between the larger vessel and the wooden box (See Fig 23.)

A **stirrer** consists of a small perforated disc of thin copper attached to a piece of wire.

Heat which is absorbed or given out by a body at constant temperature during change of state is called **latent** heat

The **latent heat of fusion of a solid** is the number of calories required to change one gram of the solid into its liquid without change of temperature

The **latent heat of fusion of ice** is the number of calories required to change one gram of ice at $0° C$ to water at $0°C$

The **latent heat of vaporization of a liquid** is the number of calories required to change one gram of the liquid at its boiling point into vapour without change of temperature

The **latent heat of vaporization of water** is the number of calories required to convert one gram of water at $100°C$ into steam at the same temperature

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EXPERIMENT No 34. To find the water equivalent of a calorimeter.

Weigh the calorimeter, let its mass be M_1 Pour some water into the calorimeter and weigh it again, let the mass of the water in the calorimeter be m. Take the temperature of the water and let it be t.

Heat some water in a beaker and take the temperature of the hot water, let it be T. Immediately pour some of the hot water into the calorimeter, stir the water, and note the highest temperature reached Let this temperature be Θ. Weigh the calorimeter again and let the mass of the hot water used be M. Let w be the water equivalent of the calorimeter.

The temperature of hot water has fallen through $T-\Theta$

The temperature of cold water has risen through $\Theta-t$.

And the temperature of the calorimeter has risen through $\Theta - t$

$\therefore$ Loss of heat by hot water $= M(T - \Theta)$.

Gain of heat by cold water $= m(\Theta - t)$

Gain of heat by calorimeter $= w(\Theta - t)$

Therefore total gain$= w(\Theta - t) + m(\Theta - t)$

Therefore $w(\Theta - t) + m(\Theta - t) = M(T - \Theta)$.

$\therefore w(\Theta - t) = M(T - \Theta) - m(\Theta - t)$.

$$\therefore w = \frac{M(T - \Theta) - m(\Theta - t)}{(\Theta - t)}$$

Therefore the water equivalent of the calorimeter is determined

Enter your results on the right hand page of your practical note book thus —

Date ____________

Experiment To determine the water equivalent of a calorimeter

Apparatus A balance, weights, a calorimeter, two thermometers, a beaker with water in it

Observations

(1) Mass of the empty calorimeter $= 60$ grams
(2) Mass of the calorimeter and water $= 123\ 3$ grams
(3) Initial temperature of water in the calorimeter $= 20°C$
(4) Temperature of hot water $= 38°C$
(5) Final temperature of water in the calorimeter $= 26°C$
(6) Mass of calorimeter after addition of hot water $= 157\ 8$ grams

Calculations

Mass of cold water $= 63\ 3$ grams
Mass of hot water $= 34\ 5$ grams

The temperature of hot water has fallen through $38-26=12^\circ C$
The temperature of cold water has risen through $26-20=6^\circ C$

Loss of heat by hot water $= 34{\cdot}5 \times 12 = 414$ calories
And gain of heat by cold water $= 63{\cdot}3 \times 6 = 379{\cdot}8$ calories
Gain of heat by calorimeter $= 6\,w$

$$6\,w + 379{\cdot}8 = 414$$
$$\therefore 6\,w = 34{\cdot}2$$
$$\therefore w = 5{\cdot}7$$

Result. Water equivalent of the calorimeter $= 5{\cdot}7$ grams

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How

EXPERIMENT No. 35. To determine the specific heat of a metal. by Copper

Take a piece of the metal and weigh it. Let its mass be M. Boil some water in a beaker and suspend the metal in the water by means of a thread. Take the temperature of the boiling water and let it be T.

Weigh a calorimeter, let its mass be M_1, and let w be the water equivalent of the calorimeter. Put some water into the calorimeter and weigh it again, and let the mass of the water in the calorimeter be m. Take the temperature of the water in the calorimeter and let it be t. When the metal has taken the temperature T of the boiling water, remove it, shake off the adhering water and plunge it immediately into the water in the calorimeter. Stir the water and note the highest temperature reached. Let this temperature be Θ. Let S be the specific heat of the metal.

The temperature of the metal has fallen through $T-\Theta$

The temperature of water has risen through $\Theta-t$

The temperature of calorimeter has risen through $\Theta-t$

$\therefore$ Heat lost by the metal $= MS(T-\Theta)$

Heat gained by the water $= m(\Theta-t)$

Heat gained by the calorimeter $= w(\Theta-t)$

Therefore $MS(T-\Theta) = m(\Theta-t) + w(\Theta-t)$

$= (m+w)(\Theta-t)$

$$\text{Therefore } S = \frac{(m+w)(\Theta-t)}{M(T-\Theta)}$$

Therefore the specific heat of the metal is determined

Enter your results on the right-hand page of your practical note book thus —

Date____________

Experiment. To determine the specific heat of copper

Apparatus A balance, weights, a piece of copper, two thermometers, a beaker, some water

Observations

(1) Mass of calorimeter = 60 grams
(2) Mass of calorimeter and water = 123 3 grams
(3) Initial temperature of water in the calorimeter 20° *C*
(4) Mass of copper = 100 grams
(5) Temperature of copper = 98 5° *C*
(6) Final temperature of water = 29 5° *C*
(7) Water equivalent of the calorimeter = 5 7 grams.

Calculations.

Mass of water in the calorimeter $= 63 \cdot 3$ grams

The temperature of the metal has fallen through $98 \cdot 5 - 29 \cdot 5 = 69^\circ C$

The temperature of the water has risen through $29 \cdot 5 - 20 = 9 \cdot 5^\circ C$

The temperature of the calorimeter has risen through $29 \cdot 5 - 20 = 9 \cdot 5^\circ C$

$\therefore$ Loss of heat by copper $= 100 \times S \times 69 = 6900\,S$ calories

Gain of heat by water $= 63 \cdot 3 \times 9 \cdot 5 = 601 \cdot 35$ calories

Gain of heat by calorimeter $= 5 \cdot 7 \times 9 \cdot 5 = 54 \cdot 15$ calories

$\therefore$ total gain $= 655 \cdot 5$ calories

$$\therefore\ 6900\,S = 655 \cdot 5,\ \therefore S = \frac{655 \cdot 5}{6900} = \cdot 095$$

Result Specific heat of copper $= \cdot 095$

EXPERIMENT No. 36. To determine the latent heat of fusion of ice.

Weigh a calorimeter, and let its mass be M_1, and let w be the water equivalent of the calorimeter Place some water into the calorimeter and weigh it again, and let the mass of the water in the calorimeter be m Take the temperature of the water and let it be t Take a few small pieces of melting ice, dry them with a blotting paper and put them into the water in the calorimeter by means of a blotting paper. Stir the water, and when all the ice is just melted, note the lowest temperature reached Let this temperature be θ. Weigh the calorimeter again and let M be the mass of the ice added Let L be the latent heat of ice

The temperature of water has fallen through $t-\Theta$.

The temperature of calorimeter has fallen through $t-\Theta$.

$\therefore$ Heat lost by water $= m(t-\Theta)$

Heat lost by calorimeter $= w(t-\Theta)$

Therefore the total loss of heat $=(m+w)(t-\Theta)$

Heat gained by ice in change of state $= ML$

Heat gained by ice-water in raising its temperature from $0°C.$ to $\Theta°C$, $= M\Theta$

Therefore the total gain of heat $= ML + M\Theta$.

$\therefore ML + M\Theta = (m+w)(t-\Theta)$

$\therefore ML = (m+w)(t-\Theta) - M\Theta$

$$\therefore L = \frac{(m+w)(t-\Theta) - M\Theta}{M}$$

Therefore the latent heat of ice is determined

Enter your results on the right-hand page of your practical note book thus —

Date____________

Experiment To determine the latent heat of ice

Apparatus A calorimeter, a thermometer, water, ice, a balance, weights

Observations

(1) Mass of empty calorimeter $=$ 60 grams

(2) Mass of calorimeter and water $=$ 123·3 grams

(3) Initial temperature of water $= 20°\ C$

(4) Final temperature of water $= 12°\ C$

(5) Mass of calorimeter after addition of ice $=$ 129·3 grams

(6) Water equivalent of the calorimeter used $=$ 5·7 grams

Calculations

Mass of water in the calorimeter $=$ 63·3 grams

Mass of ice melted $=$ 6 grams.

The temperature of water has fallen through $20-12=8°C$.

The temperature of calorimeter has fallen through $20-12 = 8°C$

Heat lost by water $= 63\cdot3 \times 8 = 506\cdot4$ calories

Heat lost by calorimeter $= 5\ 7 \times 8 = 45\cdot6$ calories

Total loss of heat $= 552$ calories

Gain of heat by 6 grams of ice in change of state $= 6L$

Gain of heat by 6 grams of ice-water in raising its temperature from $0°C$ to $12°C$ $= 6 \times 12 = 72$ calories

∴ Total gain $= 6L + 72$

$6L+72=552, \quad 6L=480, \quad L=80$

Result The latent heat of ice $= 80$

EXPERIMENT No 37 To determine the latent heat of vaporization of water, usually called the latent heat of steam.

Put some water into a flask, and fit the flask with a two-hole cork Through one hole pass a thermometer vertically so that the bulb of the thermometer is about two inches above the level of the water in the flask and the boiling point mark is just above the cork Through the other hole pass a bent glass tube and connect the other end of this glass tube to one end of a water-trap so that any condensed water carried with the steam is caught by the trap Through the other end of the water-trap pass a short delivery tube Set the water to boil

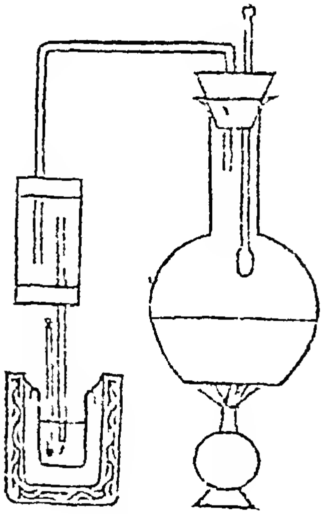

Fig 23

Weigh a calorimeter and let its mass be M_1, and let w be the water equivalent of the calorimeter. Put some cold water into the calorimeter, and weigh it again, and let m be the mass of the water in the calorimeter. When the steam is freely passing from the flask, take the temperature of the cold water and let it be t Note the temperature of the steam and let it be T Then immediately dip the end of the delivery tube into the water in the calorimeter. When the temperature of the water in the calorimeter has risen about 20° C. above its initial temperature, remove the delivery tube from the calorimeter, stir the water and note the highest temperature reached Let this temperature be Θ Weigh the calorimeter again and let M be the mass of the steam condensed Let L be the latent heat of steam

The temperature of water in the calorimeter has risen through $(\Theta - t)$.

The temperature of the calorimeter has risen through $(\Theta - t)$.

Loss of heat by steam in change of state $= ML$.

Loss of heat by M grams of steam-water in falling from $T°C$ to $\Theta°C. = M(T - \Theta)$.

Therefore total loss of heat $= ML + M(T - \Theta)$.

Gain of heat by water in the calorimeter $= m(\Theta - t)$.

Gain of heat by the calorimeter $= w(\Theta - t)$

Therefore total gain of heat $= (m + w)(\Theta - t)$.

Therefore $ML + M(T - \Theta) = (m + w)(\Theta - t)$.

$$\therefore ML = (m + w)(\Theta - t) - M(T - \Theta)$$

$$\therefore L = \frac{(m + w)(\Theta - t) - M(T - \Theta)}{M}.$$

Therefore the latent heat of steam is determined

Enter your results on the right-hand page of your practical note book thus —

Date____________

Experiment. To determine the latent heat of steam

Apparatus A flask fitted with a two-hole cork and a water trap, two thermometers, a calorimeter, water, a balance, weights

Observations

(1) Mass of the calorimeter = 60 grams

(2) Mass of the calorimeter and water = 134 3 grams

(3) Initial temperature of water in the calorimeter = $20°C$

(4) Temperature of steam = $99°C$

(5) Final temperature of water in the calorimeter = $35°C$

(6) Mass of the calorimeter after steam is condensed = 136 3 grams

(7) Water equivalent of the calorimeter used = 5 7 grams

Calculations

Mass of water in the calorimeter = $134\ 3 - 60 = 74 \cdot 3$ grams

Mass of steam used = $136\ 3 - 134\ 3 = 2$ grams

The temperature of the water in the calorimeter has risen through $35 - 20 = 15°C$

The temperature of the calorimeter has risen through $35 - 20 = 15°C$

Loss of heat by 2 grams of steam in change of state = $2\ L$ calories

Loss of heat by 2 grams of steam water in falling from $99°C$. to $35°C = 2 \times 64 = 128$ calories

Total loss of heat = $2L + 128$

Gain of heat by water = $74 \cdot 3 \times 15 = 1114\ 5$ calories

Gain of heat by calorimeter = $5 \cdot 7 \times 15 = 85 \cdot 5$ calories

Total gain of heat = $1114 \cdot 5 + 85\ 5 = 1200$ calories.

$2\ L + 128 = 1200 \qquad 2\ L = 1072 \qquad L = 536.$

Result. The latent heat of steam = 536.

MELTING POINT OF A SOLID.

The **melting point** of a solid is the temperature at which the solid melts, and this temperature remains constant from the time melting or fusion begins until the time it is completed

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EXPERIMENT No 38 To determine the melting point of wax.

Draw out a piece of fine glass tubing about two inches long Melt a little wax in a crucible, suck a little melted wax into the fine end and close the end by means of a flame Fasten this tubing along side the bulb of a thermometer with a piece of thread Support this thermometer on a water bath so that the upper end of the fine tube is above the level of the water in the bath Heat the bath gently Note the temperature at which the wax melts Remove the flame and note the temperature when the wax begins to solidify Take the mean of the two temperatures, and the mean temperature is the melting point of wax

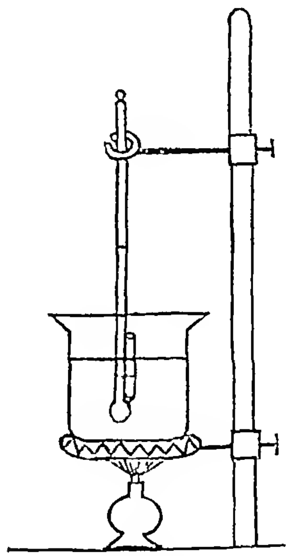

Fig 24

Enter your results on the right hand page of your practical note book thus —

Date______________

Experiment. To determine the melting point of wax

Apparatus. A fine glass tubing containing wax, a beaker containing water, a thermometer

Observations and Result

Wax begins to melt	50°C
Wax begins to solidify	49 5°C
Mean value .	49·7°C

EXPERIMENT No. 39. To determine the melting point of naphthalene.

Introduce some powdered naphthalene into a test-tube, and place a thermometer into it so that the bulb of the thermometer is wholly inside the powder Support the test tube on a bath of water so that the level of the water in the bath is just above the level of the naphthalene in the tube Insert a thermometer into the bath and heat the bath gently till the temperature of the bath is 80°C When the naphthalene in contact with the walls of the test tube begins to melt, stir the naphthalene very gently with the thermo-

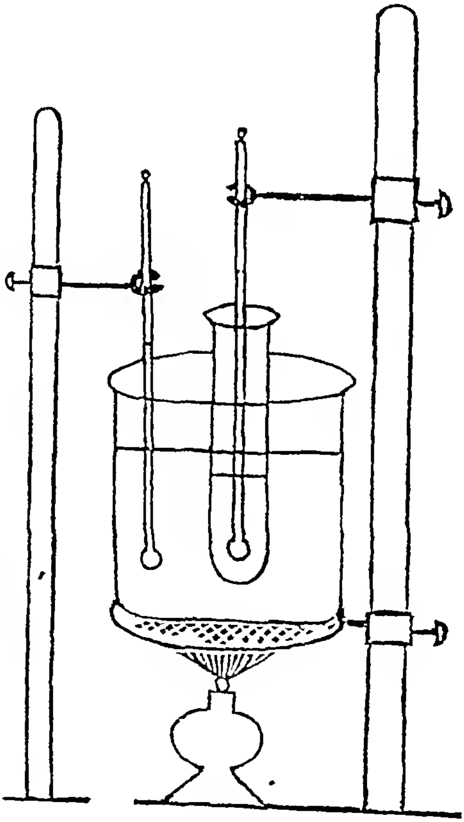

Fig 25

meter, taking care not to break the test tube or the thermometer When the naphthalene near the bulb of the thermometer begins to melt and allows the bulb of the thermometer to be seen through it, remove the flame, and read the temperature of the naphthalene This temperature which will be found to be constant for some time is the melting point of naphthalene

Enter your results on the right-hand page of your practical note book thus —

Date____________

Experiment To determine the melting point of naphthalene

Apparatus A test tube, a beaker, water, two thermometers, naphthalene

Observation and Result Melting point of naphthalene 79°*C*

BOILING POINT.

The **boiling point** of a liquid is the temperature at which the liquid boils, and this temperature remains constant during boiling The boiling point of a liquid depends upon the pressure of the atmosphere, so the boiling point of a liquid is usually defined as the temperature at which the liquid boils when the barometer reads 760 *mm.*

Precautions in determining the boiling point of a liquid.

(1) The bulb of the thermometer should be placed in the vapour of the boiling liquid and not in the liquid itself

(2) As much stem of the thermometer as possible should be surrounded with the vapour of the liquid

(3) The barometer should be read at the time of determining the boiling point

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To show that the boiling point of water depends upon pressure.

Take a round-bottomed flask, and take a good cork which tightly fits the mouth of the flask Place some water in the flask till it is about half full, and set the water to boil. When the water has boiled freely for some time, and when the air in the flask is expelled and its place is occupied by the water vapour, **first** remove the source of heat, and **then** cork the flask tightly Invert the flask over a suitable stand When the boiling has entirely ceased pour some cold water, or place some pieces of ice folded in a handkerchief over the bottom of the

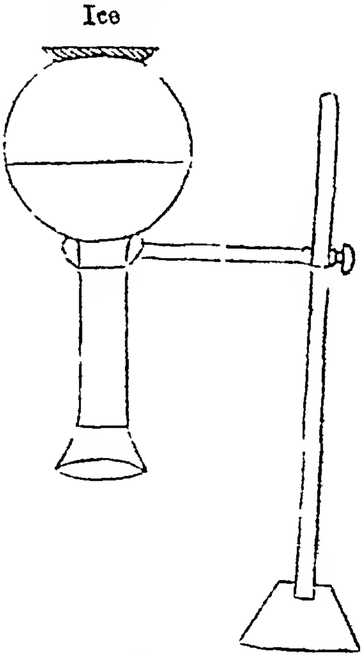

Fig 26

flask Water again begins to boil, because the vapour inside the flask is condensed and so its pressure on the surface of the water is reduced

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EXPERIMENT No 40 To determine the boiling point of alcohol.

Take a small flask and introduce into it some alcohol Fit the flask with a two-hole cork Through one hole pass a delivery tube the other end of which passes into a receiver in which the vapour of the alcohol may be condensed Through the other hole pass a thermometer so that the bulb of the thermometer is about two inches above the level of the alcohol in the flask Support the flask on a shallow bath of water in such a way that the level of the

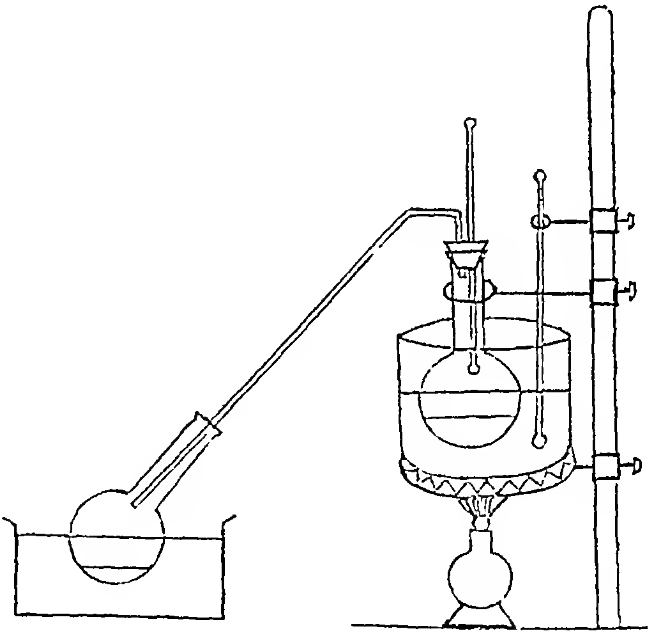

Fig 27

water in the bath is a little above the level of the alcohol Insert a thermometer into the bath and heat the bath gently. When the indication on the thermometer in the flask has become stationary, note the temperature and remove the flame This temperature is the boiling point of alcohol Read the barometer also The boiling point of carbon tetrachloride, or any other liquid whose boiling point is below 100°*C.* is determined in the same way

Enter your results on the right-hand page of your practical note book thus —

Date__________

Experiment. To determine the boiling point of alcohol

Apparatus A flask fitted with a two hole cork and a delivery tube, a receiver, water, alcohol, two thermometers

Observations (1) Boiling point of alcohol, 77 9°*C*
(2) Height of the barometer, 750 *mm*

Result. Boiling point of alcohol is 77 9°*C* at 750 *mm* pressure

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TABLES FOR REFERENCE.

(1) Melting Points.

Butter	... 33°*C*	Paraffin	... 54°*C.*
Ice	... 0°*C*	Sulphur	... 115°*C*
Lard	... 33°*C*	White wax	... 68°*C.*
Naphthalene	... 80°*C*		

(2) Boiling Points

Alcohol	... 78·3°*C.*	Ether	... 35°*C*
Carbon Tetrachloride	... 77°*C.*	Mercury	... 357°*C*
		Water	... 100°*C.*

(3) Specific Heats.

Aluminium ...	... ·214.	Iron ...	... ·114.
Brass ...	... ·094.	Lead ...	... ·031
Copper ...	... ·095	Zinc ...	... ·095

(4) Latent Heats.

Ice ...	... 79 4	Steam ...	... 536

EXAMPLES ON CHAPTER III.

On thermometers.

(1) The temperature of a person is 98·6° *F*. What is it on the Centigrade scale? (Ans. 37°*C*)

(2) What is that temperature whose Centigrade reading is half of the Fahrenheit reading? (Ans. 160°*C*)

Solution

Let x be the temperature on the Centigrade scale. Then, putting x for C and $2x$ for F in the equation

$$\frac{F-32}{9}=\frac{C}{5}, \text{ we have } \frac{2x-32}{9}=\frac{x}{5},$$

$$\text{or } 10x-160=9x, \therefore x=160.$$

(3) What is that temperature whose Fahrenheit and Centigrade readings are represented by the same number? (Ans. $-40°$)

{ Solution.

Let x be the reading on the two thermometers, then, putting x for C and F in the equation

$$\frac{F-32}{9}=\frac{C}{5}, \text{ we have } \frac{x-32}{9}=\frac{x}{5},$$

$$\text{or } 5x-160=9x, \therefore x=-40^\circ \}$$

(4) What is that temperature whose Centigrade reading is equal to the sum of the Fahrenheit and Reaumur readings? (Ans. $-20^\circ C$, $-4^\circ F$, $-16^\circ R$.)

{ Solution

Let x, y, and z be the Fahrenheit, Centigrade, and Reaumur readings respectively. Then, putting x for F, y for C, and z for R in the equations

$$\frac{F-32}{9}=\frac{C}{5}=\frac{R}{4}, \text{ we have } \frac{x-32}{9}=\frac{y}{5}=\frac{z}{4}$$

$$\therefore x=\frac{9}{5}y+32, \qquad (1)$$

$$\text{and } z=\frac{4}{5}y, \qquad (2)$$

$$\text{and by the question } y=x+z \qquad (3)$$

$\therefore$ Substituting from (1) and (2) the values of x and z in terms of y in (3), we have

$$y=\frac{9}{5}y+32+\frac{4}{5}y,$$

$$or\ y = \frac{13}{5}y + 32,$$

$$or\ y = -20,$$

and from (1) $x = -4$;

and from (2) $z = -16$ }

On Expansion.

(5) The length of an iron rod is 100 *cms* at 0°*C*. What is its length at 50°*C*, the coefficient of linear expansion of iron being ·000012? (Ans 100·06 *cms*,)

(6) The length of a gold rod is 100·3 *cms* at 200°*C* Find its length at 100°*C*, the coefficient of linear expansion of gold being ·000015 (Ans 100·15 *cms*)

{Solution

$$l_t = l_0 (1 + \beta t)$$

$$or\ 100·3 = l_0 (1 + ·000015 \times 200)$$

$$or\ 100·3 = l_0 (1 + ·003) = 1·003 \times l_0$$

$$\therefore l_0 = \frac{100·3}{1·003} = 100.$$

Again,

$$l_{100} = l_0 (1 + \beta t)$$

$$= 100 (1 + ·000015 \times 100)$$

$$= 100 \times 1·0015 = 100·15 \quad \}$$

(7) The length of a tin rod at $40^\circ C$ is $100 \cdot 1$ *cms*, and that at $80^\circ C$ is $100 \cdot 2$ *cms* Calculate the coefficient of linear expansion of tin. (Ans $\cdot 000025$)

(8) Two iron rods, each 50 *cms* long at $0^\circ C$, are placed in one straight line and have their outer ends fixed Find how far their inner ends must be apart so that they may just touch at $60^\circ C$, the coefficient of linear expansion of iron being $\cdot 000012$ (Ans. $\cdot 072$ *cms*)

(9) The length of a copper rod is found to be $\cdot 034$ *cms* longer at $80^\circ C$ than at $60^\circ C$ Find its length at $100^\circ C$, the coefficient of linear expansion of copper being $\cdot 000017$. (Ans $100 \cdot 17$ *cms*)

Solution

$$l_{80} = l_0 (1 + \beta 80).$$
$$l_{40} = l_0 (1 + \beta 40)$$
$$\therefore l_{80} - l_{40} = 20 \beta l_0$$
$$\text{or } \cdot 034 = l_0 \times 20 \times \cdot 000017,$$
$$\therefore l_0 = \frac{034}{20 \times \cdot 000017} = \frac{\cdot 034}{00034} = 100.$$
$$l_{100} = 100 (1 + \ 000017 \times 100)$$
$$= 100 + \cdot 17 = 100 \cdot 17.$$

(10) The area of a sheet of brass is $50 \cdot 18$ sq. *cms* at $100^\circ C$ Find its area at $0^\circ C$, the coefficient of linear expansion of brass being $\cdot 000018$ (Ans 50 sq *cms.*)

(11) The volume of a platinum sphere is 10·027 C. C at 100°C What will be its volume at 200°C, the coefficient of linear expansion of platinum being ·000009 ? (Ans 10 054 C C)

On quantity of heat.

(12) How many calories are required to heat 40 grams of water from 10°C to 60°C. ? (Ans 2000 calories)

(13) 10 grams of water at 30°C are mixed with 40 grams of water at 50°C Find the final temperature (Ans 46°C.)

(14) A calorimeter contains 63·3 grams of water at 20°C 34 5 grams of water at 38°C are poured into it, and the final temperature is 26° C Find the water equivalent of the calorimeter (Ans 5 7 grams)

Solution

Let w be the water equivalent of the calorimeter

Loss of heat by hot water $= 34\cdot5 \times 12 = 414$ calories

Gain of heat by cold water $= 63\cdot3 \times 6 = 379\ 8$ calories

Gain of heat by the calorimeter $= w \times 6 = 6w$.

Loss = Gain

$\therefore\ 6w + 379\ 8 = 414$

$\therefore\ 6w = 34\ 2, \ \therefore\ w = 5\cdot7$ grams.

(15) A copper calorimeter whose mass is 60 grams contains 63·3 grams of water at 20°*C.* 100 grams of copper at 98 5°*C* are plunged into the water and the resulting temperature is 29 5°*C* Determine the specific heat of copper (Ans. ·095)

(16) 20 grams of ice at 0°*C* are put into 300 grams of water at 16°*C* Find the final temperature. the latent heat of fusion of ice being 80. (Ans 10°*C*)

(17) A calorimeter contains 63·3 grams of water at 20°*C.* 6 grams of ice at 0°*C* are put into the water and the resulting temperature when the ice is just melted is 12°*C* Find the latent heat of ice, the water equivalent of the calorimeter being 5·7 grams (Ans 80 calories.)

(18) A copper calorimeter whose mass is 60 grams contains 74·3 grams of water at 20°*C.* 2 grams of steam at 99°*C.* are condensed into the water and the final temperature is 35°*C.* Determine the latent heat of steam, the specific heat of copper being ·095. (Ans. 536 calories)

(19) How much ice can be melted by 50 grams of steam at 100°*C.*, the latent heat of fusion of ice being 80, and the latent heat of steam being 536. (Ans 397·5 grams)

(20) If the latent heat of steam be 536 when 1° Centigrade is the unit of temperature, what will it be when 1° Fahrenheit is the unit of temperature? (Ans 964·8.)

(21) A calorimeter the water equivalent of which is 5 grams, contains 91 grams of water at $80°C$ 6 grams of ice at $-20°C$ are added to the water Find the final temperature, the specific heat of ice $= \cdot 5$, the latent heat of ice $= 80$ (Ans $70°C$)

Solution

Let θ be the final temperature,

loss of heat by water $= 91(80-\theta)$,

loss of heat by calorimeter $= 5(80-\theta)$,

$\therefore$ total loss $= 96(80-\theta) = 7680 - 96\theta$

Gain of heat by ice in change of temperature

$$6 \times \cdot 5 \times 20 = 60,$$

gain of heat by ice in change of state 6×80

$$= 480,$$

gain of heat by ice water $= 6\theta$,

$\therefore$ total gain $= 60 + 480 + 6\theta = 540 + 6\theta$.

$\therefore 540 + 6\theta = 7680 - 96\theta$

$$102\theta = 7140, \therefore \theta = 70°.$$

(22) A calorimeter, the water equivalent of which is 5 grams, contains a mixture of 15 grams of ice at $0°C$ and 60 grams of water at $0°C$ 8 grams of steam at $100°C$ are passed into the mixture Find the final temperature, being given that the latent heat of steam $= 534$, and the latent heat of ice $= 80°$. (Ans $44°C$)

QUESTIONS ON CHAPTER III.

(Selected from Allahabad University Matriculation Papers.)

1 Describe the construction of a thermometer. (1914)

2 Given an ungraduated thermometer, how would you graduate it? (1911)

3. What are the fixed points of a thermometer? Describe carefully how they are determined. How would you convert a Fahrenheit into a Centigrade temperature? Find graphically or otherwise the temperature at which the Fahrenheit and the Centigrade thermometers give the same reading. (1908, 1915)

4 How would you find the error in a thermometer at the boiling point of water? (1910)

5 What is meant by **coefficient of expansion**? A copper wire is found to be 0·034 *cms* longer at 25°*C.* than at 5°*C.* Calculate accurately what its length would be at 0°*C*, coefficient of expansion of copper = ·000017. (1909)

6 Describe accurately a calorimeter. Explain why the different parts are so constructed. (1912)

7 What does 'the water equivalent of a calorimeter mean? How would you find it for a given calorimeter? (1910)

8 Explain what is meant by the specific heat of a substance. How would you measure the specific

heat of copper? (1911) How would you find the specific heat of lead? (1914)

9 Explain quite clearly what you mean by **latent heat** How would you determine the latent heat of evaporation of water? (1915)

10. If we pass steam at 100° into a kilogram of water at 0° until the temperature is raised to 100°, it is found that weight of the water is 1 187 kilos. Explain the meaning of this and show how the latent heat of steam can be calculated (1912)

11 How many units of heat would it take to raise the temperature of 50 grams of ice at $-10°C.$ and convert it into steam at $100°C$, the specific heat of ice is 5, and the latent heats of water and steam are 80 and 540 respectively. (1913)

12 Explain how you would determine the melting point of a given solid. Make a neat diagram of the apparatus employed (1913)

13 Describe an experiment showing that the boiling point of water depends upon pressure. (1913)

14 What precautions have to be taken in determining the boiling point of a liquid Explain carefully how you would determine the boiling point of a given liquid Give a neat diagram of the apparatus you would use (1909, 1910)